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THE APPLICATION OF
STATISTICAL PROCESS CONTROL
IN NON-MANUFACTURING ACTIVITIES

by

LAWRENCE WILLIAM OLSON
Captain, USAF
1987

191 pages

Master of Science in Industrial Engineering
University of Illinois at Urbana-Champaign

ABSTRACT

Statistical process control (SPC), as espoused by Dr. W. Edwards Deming and Walter A. Shewhart before him, is both a quality control methodology and a quality philosophy that directly relates productivity improvement with quality improvement. This methodology is gaining popularity among mass production industries with dramatic demonstrations of concurrent improvements in quality and productivity. This paper proposes that the methods and philosophy of SPC are equally applicable to every type of non-manufacturing activity and will result in similar increases in quality and productivity. The concepts and techniques of SPC are translated into non-manufacturing terms supported by examples from the literature. A three stage process is proposed to guide a manager in the implementation of SPC and this process is demonstrated in the production control section of an Air Force civil engineering squadron.

THE APPLICATION OF
STATISTICAL PROCESS CONTROL
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BY

LAWRENCE WILLIAM OLSON

B.S., Oklahoma State University, 1981

THESIS

Submitted in partial fulfillment of the requirements
for the degree of Master of Science in Industrial Engineering
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CHAPTER 1
The Need for Quality Improvement in Non-Manufacturing Activities

The application of statistical methods to process control provides a better understanding of the behavior of any operation. This understanding is a necessary piece of management information. It is essential for making good decisions about process adjustments and assessing the effect of process improvement actions. The use of statistical methods also makes this understanding available to the employees who are actually working the processes. Fortunately it is not necessary to understand a great deal about the mathematics of statistical theory in order to make full use of statistical methods. The concepts and techniques of a methodology known as statistical process control (SPC) form a repertoire of powerful statistical tools that are effective in bringing about concurrent improvements in both quality and productivity. Although the development of statistical process control required relatively advanced statistical analysis only an elementary understanding of statistics is required to make use of these techniques.

When statistical process control techniques are coupled with some widely used problem solving techniques, a manager has the means to conduct a continuous program of quality and productivity improvement. In such circumstances a manager can be confident in his ability to maintain a competitive advantage. Putting this in non-profit terms, the manager can be confident in his ability to accomplish all assigned missions within the allotted or available budget. In both profit and non-profit organizations it is no longer possible to rely on increased

spending or capital investments to bring about increased production capacity.

Statistical process control is a means of quality control that employs Shewhart control charts to study the variation in the production process. This approach is best understood when contrasted with the traditional approach to quality control that inspects finished product for conformance to certain specifications. This inspection may involve only a sample of the output or every unit of output. When a sample is used a judgment is made on the entire lot based on a prescribed lot sampling scheme. One hundred percent inspection is merely an effort to sort the defective output from the good output. Statistical process control, on the other hand, concentrates on reducing the variation in the production process; and, as a result, the chance of producing defective output is reduced. Process variation is reduced by removing faults in the process and this results in increased productivity.

The Prevalence of Quality/Productivity Improvement Efforts

The use of the word "process" brings to mind the mechanical processes of product manufacturing. Thus, the manager of a non-manufacturing activity is inclined to dismiss these ideas as not applicable to his operations. Nevertheless, a search of recent literature reveals a great deal of interest in improving the quality and productivity of non-manufacturing industries. Following are a few examples that show the prevalence of various quality and productivity efforts.

The United States Fidelity and Guaranty Company of Baltimore has implemented four methods as part of their service quality improvement program (Zimmerman 1985). The first method is error identification.

Random sampling is used to find errors and return them to the responsible employee for correction. The second method is error analysis. This involves employees and supervisors at all levels. Pareto analysis and trend analysis are two of the most frequently used tools. The third method is corrective action. Short-range corrective action programs are developed in response to sporadic error problems. The fourth method is ongoing enhancement. This incorporates quality concepts in the development of new goods and services.

The Fram Corporation monitors the percentage of line items in error on shipments from its distribution center for individual work groups. Their objective is to force the error percentage to zero by periodically lowering the goal as a group's error percentage drops. The motivation is the fact that errors in distribution completely nullify all efforts to produce a good product (Martin 1985).

The Paul Revere Life Insurance Company of Worcester, Massachusetts has implemented a program known as "Quality Has Value". They employ a modified quality circle technique to generate improvement ideas from the employees and promote top management participation in the improvement process (Townsend 1985).

Blue Cross of Western Pennsylvania has applied a technique they call process management to their clerical operations (Connell 1967) and the Continental Illinois Bank in Chicago has done the same (Aubrey and Eldridge 1981).

Process capability analysis has been applied to the production of the Consumer Price Index and The Production Price Index at the Bureau of Labor Statistics in an effort to make these measurements more reliable (Dmytrow 1985).

The Hartford Insurance Group and International Telephone and Telegraph both know the value of improving quality and demonstrate this understanding by practicing a detailed quality improvement process (Scanlon and Hagan 1983a and 1983b).

The Sheraton Corporation is deeply committed to improving the quality of service in their hotels (Mellin 1977). Their efforts include several participative management programs and the enhancement of individual worker identification with the job.

The Eaton Corporation is using a variety of quality improvement techniques in its Materials Handling Parts Distribution Center (Janas 1976).

James E. Olson, President of AT&T, is convinced that quality improvement efforts are sound business investments, and says that statistical analysis of everything they do is crucial to their success (Olson 1985).

From among all the examples found, IBM and Ford stand out as pioneers in the implementation of statistical process control. They were among the first to use statistical process control in their manufacturing processes and now they are using these techniques in a wide variety of non-manufacturing processes. The Ford Motor Company, for example, has revised its personnel performance appraisal system from the perspective of statistical process control because it was a "barrier to continuous improvement and quality performance" (Scherkenbach 1985). They have also used statistical process control at their Windsor Export Supply Company to improve their accounts payable process (Baker and Artinian 1985). See also Sullivan (1984) for a clear pre-

sentation of Ford's approach to quality through the reduction of process variability.

The IBM Corporation uses statistical process control in its National Marketing Division (Nickell 1985) and has employed these techniques in a number of support activities in their site services operation at their Kingston, New York facility (McCabe 1985).

In each of the other examples, effort has been concentrated in the identification and containment of poor quality, or in the solicitation of improvement ideas from employees. Examples of the use of statistical process control as a quality and productivity improvement tool are still rare. Marc Holzer (1983) in an editorial in a recent issue of Public Productivity Review listed the following subjects and strategies that are currently on the minds of most public sector specialists: "measurement and performance auditing; automation and robotics; Japanese Management and Quality Circles; worker participation in managerial decisions and management participation in front-line work; investments in machinery and investments in people; feedback from and to employees; contracting out and contracting in." Notice the absence of statistical process control. This is not necessarily true in the manufacturing area, however. A recently published survey by the Automobile Industry Action Group (Southfield, MI) of 275 companies that supply parts to the automotive industry cite statistical process control as more important to productivity improvement than bar coding, just-in-time delivery, or electronic communication (Farnum and Gayman 1987).

The Need for Statistical Process Control

On February 25, 1986 President Reagan issued an executive order that established a comprehensive productivity improvement program for the federal government. Benda and Levine (1986) had the following to say about this proclamation. "Improving productivity in the federal government has been an enduring, recurrent, yet elusive goal. Among the problems endemic to productivity improvement in the federal sector is...the need to devise measurement systems that control not only for the quantity of output but for the quality and timeliness of service provision as well."

In many of the examples cited above the authors lamented the fact that little practical guidance existed to help implement any type of quality and productivity improvement program for non-manufacturing areas. For example, Melan (1985) of IBM, Kingston said that quality principles in general have not been widely applied to non-product activities; and McCabe (1985), also of IBM, Kingston, had this to say about their quality improvement efforts, "Among other problems, most texts on the subject [of control charts] treated it in manufacturing terms, adding that the concepts could apply equally well to service organizations." Anyanonu and Bajaria (1980) put it this way, "Quality control principles are well translated for product and construction industries, but have not yet paved a roadway into many service industries."

It is true that statistical process control had its origin in manufacturing and that the concepts and techniques are all explained in manufacturing terms. Most instructional material on the subject is also couched in manufacturing terms. This is enough to discourage any

manager of non-manufacturing activities from attempting to make use of these powerful tools.

Purpose

The primary purpose of this thesis is to translate the concepts and techniques of statistical process control into terms useful to managers of non-manufacturing activities. This will not be a direct translation because the terminology of statistical process control will not be altered. Instead, the definition of these terms will be expanded to include the non-manufacturing environment. This will be accomplished by constructing direct analogies between the elements of a manufacturing environment and those of a non-manufacturing environment. It is necessary for the manager of non-manufacturing activities to understand how the concepts and techniques of statistical process control can be directly applied to any type of activity.

Three objectives will be pursued in support of this primary purpose. The first objective is to persuade managers that these concepts and techniques are essential management tools. It is easy for managers to be content relying on their intuition and familiar management techniques especially if they are successful. The benefits available from the use of statistical process control are such that even successful operations can realize significant improvements in quality, productivity, and production capacity. This gain potential makes the use of statistical process control indispensible. Many large manufacturing companies, such as Ford and IBM, believe so strongly in the benefits of statistical process control that they require their suppliers to employ these techniques in all aspects of their manufacturing activities (Ford 1984).

The second objective is to provide managers with a means to employ these concepts and techniques in their individual areas of responsibility. The intention is to help managers change a vague notion that things should be better into a series of specific actions that will yield measureable results. Many management decisions are made under conditions of uncertainty. Statistical process control can make the conditions under which these decisions are made more certain by reducing the variational noise in the process, and it can also make the evaluation of the effects of these decisions more definite. The continuing use of statistical process control provides a history of process behavior against which the effects of any improvements or changes can be evaluated.

The third objective is to show individual branch or department managers that they can effect significant improvements in both quality and productivity apart from the environment of a formal quality/productivity improvement program promoted or sponsored by top management. Most of the literature and consultation advice emphasizes that the sponsorship of top management is necessary for a quality/productivity improvement program to be successful. (See, for example, Langevin 1977, Crosby 1979, Crosby 1984, and Price 1984.) This advice is valid but it suggests that the first task of a concerned first-line manager is to convince top management to support a company-wide program and this may discourage any autonomous effort. Effort should be expended on this task but it need not preclude concurrent efforts by the first-line manager to implement a small scale program in his own area of responsibility. Success on a small scale may be what is needed to convince top management that a company-wide program

is necessary. It is also important for a concerned manager to know that he does not need for a quality assurance division to be formed in order to help him out.

It is expressly not the purpose of this thesis to repeat the mathematical details of the construction of various types of Shewhart control charts nor the statistical basis for their interpretation. Although the correct use and interpretation of Shewhart control charts serve as the backbone of statistical process control, the details of their construction and their interpretation rules are readily available in other references. (See Grant and Leavenworth 1980 or Oakland 1986, for example.)

Corporate Culture

A solo effort may not be easy for many, however. The manner in which an organization or corporation typically conducts its daily business can be called that organization's culture. Too many organizations have cultures that inhibit the quality improvement process. Melan (1987) says this is due to the heirarchical structure coupled with the fact that work unit performance is measured on output quantity rather than on how that output affects the work unit that must use it. Juran (1964) called this phenomenon provincialism where people work energetically to achieve their own objectives while the collective good of the organization suffers. Ishikawa (1985) refers to this situation as sectionalism, and Hermann and Baker (1985) call it parochialism.

The ultimate aim of a quality improvement program is to achieve a change in the organizational culture. This change does not occur easily nor quickly. This is the primary reason consultants advocate

that any improvement program be sponsored and promoted by top management. This does make the change easier but not much faster. Such a situation is discouraging for a first-line manager who is genuinely concerned about improving the quality of his output. Such a manager may have to sacrifice personal or department objectives temporarily in order to achieve real quality improvement, rather than merely an increase in output quantity.

Sullivan (1987) suggests that strengthening horizontal technical interaction within an organization is a means to change the organizational culture and maximize quality improvement and cost reduction. An innovative manager may be able to foster some of this interaction with his immediately surrounding work environment. Hermann and Baker (1985) suggest the use of interlocking objectives to accomplish this end. Olson (1985) says that a way to lead a cultural change in an organization is to have a quality policy statement that is more than just words; meaning that top management and every one else must live by that policy.

Some Misunderstanding About SPC

There are two prevalent ideas concerning statistical process control that need to be refuted. The first is the idea that statistical process control is only applicable to manufacturing, and the second is the idea that quality improvement can only be achieved through sacrifices in productivity. The first notion reflects the same kind of difficulties early practitioners of quality control had in convincing manufacturers that statistical process control could be applied to any type of product. This same difficulty now exists in convincing service managers that statistical process control is applicable to any

type of work activity. Both J. M. Juran (1979) and W. Edwards Deming (1982) have been teaching this for years, but the service industries have been slow in picking it up. The second notion reflects the understanding most people have regarding high quality; the better a product or service is the more it is going to cost.

This work is intended for the manager of non-manufacturing activities and mainly for the first-line manager. It will also be of interest to those in upper management because supervision and management can also be considered non-manufacturing activities and thus are amenable to statistical process control.

Characteristics of Non-Manufacturing Activities

Non-manufacturing includes a broad range of activities. As the term suggests, everything that is not involved with the direct production or manufacture of products is included. The line between manufacturing and non-manufacturing can sometimes be fuzzy but a clear distinction between the two is not necessary. The principles set forth in this thesis will make it possible to understand and apply statistical process control to any activity.

Non-manufacturing activities can be divided into two broad categories: service operations and support functions. Service operations include everything traditionally thought of as service industries. A partial list would include the following services: janitorial, personal services, transportation, food and lodging, legal, medical, financial, communication, engineering, architecture, and consultation. Also included would be education. religious, insurance, real estate, psychological counseling, marketing and advertising, maintenance, sec-

urity, wholesale and retail trade, entertainment, and public utilities.

Another group of activities that can be included with services are the tasks performed by federal, state, and local governments. These services range from police and fire protection at the local level to national defense and foreign policy on the federal level.

Support activities consist of those activities that support the primary mission of an organization, whether this mission is the manufacture of a product or the provision of a service. These include all clerical and administration activities, as well as management and supervision. Functions such as quality control, inspection, production control, inventory control, personnel, and financial management are also included.

The Prevalence of Non-Manufacturing Activities

According to the United States Bureau of Labor Statistics as reported in the 1985 Information Please Almanac, over 75% of the non-agricultural work force in 1983 was employed in services-producing industries. This figure includes government employees at all levels. Another source, the 1986 World Almanac, reported that in 1984 about 68% of the working population was employed in the following job categories: service occupations, management and professional specialties, technical sales, and administrative support. In addition, in some manufacturing industries more than 50% of the employees are engaged in administrative support activities (Scanlon and Hagan 1983a).

It is obvious from these figures that there exists a vast potential for quality and productivity improvement through the use of statistical process control, and most of the people involved in non-manu-

facturing activities have given little thought to the meaning of productivity and quality management (Scanlon and Hagan 1983a).

According to Roger Porter (1983), Director of the White House Office of Policy Development, the growth rate of national productivity has continued to decline sharply in recent years inspite of persistent efforts at improvement. He lists as one of the factors in this decline, according to most analysts, that our economy has "experienced shifts in capital and labor from one sector of the economy to another, where lower rates of growth, particularly in the more rapidly expanding service sector of our economy, exists."

Many examples of the successful application of statistical process control in manufacturing can be found in the literature. Some of these examples document the fact that significant improvements in quality and productivity are being realized in this area. This also supports the statement in the previous paragraph that productivity in non-manufacturing areas is the main reason for the decline in the national productivity growth rate. It is, therefore, imperative that statistical process control be applied to these activities in order to reverse this decline. The responsibility cannot be borne solely by manufacturing.

Manufacturing and Non-Manufacturing Compared

It is worthwhile at this point to discuss some of the aspects of non-manufacturing operations that are not found in the manufacturing setting, and later some similarities will be considered. The output of a non-manufacturing activity is often intangible. An employee communicating the status of a repair job to the customer is performing a function that has intangible output. Once the communication is com-

plete the only product that remains is the feeling of satisfaction or dissatisfaction on the part of the customer. In addition, it is not possible to inspect the product at a later time to determine its quality or to gather measurement data.

The output is also often perishable. It is not possible for a secretary to stockpile an inventory of letters to be used at a later date. The letters must be produced on demand.

In many service operations the customer is present in the production and delivery system. This introduces an unknown and largely uncontrollable factor that does not exist in manufacturing activities. In the process of selling insurance almost the entire production effort consists of an exchange of information between the customer and the sales person.

It is often difficult to determine what the customer wants and what standards he uses to evaluate the service performance. In a fine restaurant, for example, fast service may be seen as superficial and uncaring, yet service that is too slow could be viewed as incompetence or unreliability.

Finally, as the name implies, the outputs of non-manufacturing activities are not produced by a manufacturing process, but rather by performing activities that fill a need that people cannot or do not choose to meet for themselves.

There are also some important similarities that need to be recognized. The output must fit the use the customer intends for it. For an insurance company this would mean providing the correct amount of coverage for each individual's needs. There is an ability to replicate performance on an ongoing basis. The production process almost

always includes an input by a customer followed by a sequence of production events and an output that is a product or the completion of a service. A good example of this is a fast food restaurant. A customer is confident that he will receive a certain quality product at a certain price without deviation. The main purpose of statistical process control is to insure that this ability is maintained and improved. Another similarity is that the process may also be high in volume, such as the processing of checks at a bank, and is usually labor intensive. Timeliness is also a major concern to the customer. In the car repair business, the cars must be serviced and returned in a minimum amount of time. An insurance claim must be settled quickly. Customer satisfaction is the primary concern in both manufacturing and non-manufacturing activities. The customer expects to get what he pays for. If we purchase a cleaning service for our home, we expect to receive a clean house. Finally, as in manufacturing, it is also desirable to adhere to pre-established specifications. If we need emergency plumbing repair, for example, we do not expect to wait several days to get the job done.

Overview

Here is an overview of what is to follow. Chapter 2 discusses the various definitions of quality and the characteristics of a good definition of quality. Chapter 3 explains the relationship between quality and productivity. Chapter 4 translates the concepts and techniques of statistical process control for use on non-manufacturing activities. Chapter 5 outlines a step-by-step approach to implementing statistical process control and chapter 6 shows how these steps

are applied in a real situation. The organization that will be studied is a United States Air Force civil engineering squadron.

CHAPTER 2
Definition of Quality and Quality Improvement

The definition of quality that a company or organization adopts is directly related to its quality improvement activities. In other words, the activities an organization are willing to engage in for the purpose of maintaining or improving its quality are governed by its definition of quality. More often than not a non-manufacturing organization does not have an explicit definition of quality that it can call its own. In such cases each individual and each functional unit within the organization is free to come up with their own definition of quality. Since this definition will govern the way they behave toward quality improvement efforts, it is difficult to achieve a unity of purpose in the organization, and this leads to dissension between functional units; one unit's goal may not be compatible with the next unit's goal.

It is also possible that an organization may have an explicit definition of quality that applies to every functional unit, yet this definition could lead to counterproductive efforts, or at least efforts that inhibit quality and productivity improvement. For example, the definition of quality at the Fram Corporation Distribution Center (Martin 1985) is to have zero errors in all of their shipments. Such a definition can lead to excess inspection and wasteful work practices. Therefore, it is important first of all that an organization adopt a unified quality policy; and secondly, that this policy be grounded in the correct definition of quality. The correct definition of quality will open the way for continuous, never-ending improvements in both quality and productivity; and this translates

into an improved competitive position for profit making organizations and sound fiscal responsibility for nonprofit organizations.

The two main topics of this chapter will be the definition of quality and the idea of quality improvement, and how they relate to each other. In discussing the definition of quality, the characteristics of both good and bad definitions will be presented, and how these effect management decisions and worker behavior. Also, there are certain aspects that characterize good quality in the outputs of both manufacturing and non-manufacturing activities that need to be discussed because they influence both the way people traditionally think of quality and what they do to improve it.

Quality Definition in a Manufacturing Environment

It will be necessary to begin with the concepts of quality related to manufacturing activities and consider how they have evolved from the traditional concepts to the more advanced concepts of quality as espoused by Dr. Genichi Taguchi (1980); and then proceed to the non-manufacturing environment. The Taguchi definition of quality contains all the characteristics necessary for it to qualify as the correct definition. He defines quality as the losses due to functional variation and harmful effects that a product imparts to society as a whole, beginning at the time the product is shipped. The implications of this definition will be examined later in the chapter. This definition, however, is not accepted in all manufacturing circles and has not even been considered in many others. Although the definition of quality in a non-manufacturing environment has the same impact as in a manufacturing environment, there have been only a few cases where Taguchi's quality philosophy has been operationally translated

into non-manufacturing terms. (This translation does not refer to a translation from the Japanese language, but to a translation from the manufacturing context.) The full scope of Taguchi methods will not be addressed in this chapter; only those concepts relating to the definition of quality and on-line quality improvement activities. The other aspects of his methods will be addressed at one point or another throughout the remainder of this paper. The main body of Taguchi methods, however, concerns off-line quality control. The concepts and techniques of statistical process control, on the other hand, are employed in on-line quality control, so an indepth analysis of non-manufacturing activities in terms of off-line quality control concepts will not be attempted.

The search for the correct definition of quality may begin in the dictionary. The second definition listed for quality in Webster's Unabridged Dictionary (1975) is "any characteristic which may make an object good or bad; its degree of excellence". Nine additional definitions are also given demonstrating the variety of contexts in which the word may be used. None of these definitions can be used in a quality policy to promote concurrent quality and productivity improvement efforts because they direct a manager's attention to the output of a work process rather than to the operation of the work process itself. This leads to efforts designed to detect and contain low quality output and this does harm to productivity. A definition of quality that directs management attention toward improving the quality of the work process will lead to concurrent increases in output quality and process productivity.

A number of different notions come to mind when someone thinks about what it is that makes one product or service better than another product or service. Quality is a complex and multifaceted concept. Aspects of quality include performance, features, reliability, conformance, durability, serviceability, aesthetics, and perceived quality (Kackar 1986). Consider first the quality of a manufactured product. It is easy to say that a Mercedes-Benz is a better quality car than a Chevrolet, and it is possible to list a number of characteristics about the Mercedes that justify this judgment. The body may be made out of a heavier gauge steel and the paint may be thicker and more durable, and have a deeper shine. The upholstery may be leather instead of fabric, and the interior appearance may be more elegant. The Mercedes showroom may also be more elegantly appointed and the dealer may offer signature service. The Mercedes reputation for durability is also a quality characteristic, and its high quality image is supported by its high price. Another aspect of quality is the status imparted to the owner of a Mercedes.

This list could continue but it is sufficient to illustrate the three basic categories into which quality characteristics can be divided. One characterization of product quality makes a distinction between product attributes and service attributes (Thompson, DeSouza, and Gale 1985). Taguchi (1980) divides the product attributes into product species and product function. So the three basic categories of product quality are <u>product species</u>, <u>product function</u>, and <u>product service attributes</u>. Similar categories exist for non-manufacturing outputs. <u>Service level</u> is analogous to product species, and <u>service performance</u> is analogous to product function. These will be presented

in more detail later. The service attributes of product quality will also be discussed at that time since they are non-manufacturing in nature.

Product Species, Function, and Service Attributes

Product species concerns those aspects of a product's quality that are largely subjective in nature such as a product's aesthetics and the overall customer perception of quality. The depth of shine in the paint job on a Mercedes is an example of product species and so is its leather upholstery. Product function is judged by the life performance of the product; how long it lasts, its energy consumption, the frequency of maintenance and repair, and the production of harmful effects. A Mercedes' thicker paint job and heavier gauge steel body may make the body skin more resistant to rust and dents. The Mercedes may require an oil change every 15,000 miles rather than every 7,000 miles and this would also increase its quality. In addition, its ability to hold a proper wheel alignment will eliminate the harmful effects of excessive tire wear due to poor wheel alignment. Finally, the service aspects of a Mercedes' quality has to do with the appointment of the showroom and the individualized service offered by the dealer through his signature service program.

One of the first things considered when most people judge the quality of a product are the aspects of product species. For example, an effort to improve the quality of a Yugo could include such things as leather upholstered seats, walnut trim on the dash and door panels, and a walnut steering wheel. These changes would certainly improve the elegance of the car interior as well as increase the car's price, and people may also agree that its quality was improved. Product

species is what makes a customer select a fully loaded Buick Century over the base model. Quality improvements based on product species always cost more. Unfortunately, it is this kind of thinking that causes people to associate high quality with high cost.

Product function is a more subtle aspect of product quality. Just because a Yugo is a small, inexpensive car does not mean that it cannot be a high quality item. A Yugo's engine could be designed so that oil changes are required infrequently. Its wheel alignment mechanism could be designed to withstand bumps and curbs without effecting the wheel alignment. The upholstery fabric may be just as durable as leather and the interior could be attractively designed without the added expense of walnut trim. A product may function perfectly but have other negative impacts not related to its function.

Although product species and product function are both valid aspects of quality it is important to distinguish between the two when developing a definition for quality. A definition for quality based on product species will add cost to the product and not necessarily value. A definition based on product function can result in improved quality and a reduction in cost. This means added value and an improved competitive position. Cost and quality are intimately related. No one would buy a Chevrolet if a Mercedes was available at the same price. The only way for a company to improve its competitive position is to increase quality while at the same time reducing cost (Deming 1982). A product will gain market share due to quality aspects related to product species, but once it has an established market it will maintain or lose its position based on quality aspects related to product function (Taguchi 1980).

In summary, there are two ways that a product can be better than its competitor. First it might perform its intended function more effectively; and second, it might perform its intended function just as well but at a lesser cost (Price 1984).

Non-Manufacturing Quality Characteristics

Non-manufacturing quality characteristics are more elusive than quality characteristics in manufacturing. Quality control in non-manufacturing industries requires a much broader approach to quality than in the product-oriented industries. It must include elements such as the quality of human performance, equipment performance, data, decisions, and outcomes (Rosander 1980).

One way of looking at service quality is directly analogous to product species and product function. The term service level is equivalent to product species and service performance is equivalent to product function. Chauffeured limousine transportation provided by a hotel during a guest's stay is a higher service level than simply allowing a taxi stand to operate in front of the hotel. A suite in a hotel decorated with expensive furnishings and paintings is another example of high service level. Service performance, on the other hand, has to do with room cleanliness, having the room ready for occupancy when a guest arrives, insuring that everything in the room is in good repair, and that room service is prompt and reliable. Service quality is a measure of how well the service level and service performance match the customers' expectations (Lewis and Booms 1983).

Another way of looking at service quality is given by Rothman (1983). He identifies two dimensions of service quality. One is readiness to serve and the other is performance quality. The readi-

ness to serve dimension can be improved by doing something like adding more telephone operators or servicemen. For example, an airline can increase its readiness to serve by increasing the number of ticket agents behind the counter. In order to increase its performance quality, however, it would be necessary to insure that all the ticket agents were fully trained and capable of handling all possible situations with dispatch. Performance quality is similar to product function in that it is a measure of the ability of the service to accomplish its intended purpose.

Carol King (1985) refers to the technology of the service as the <u>hard functions</u>, and the manner in which the service is delivered as the <u>soft functions</u>. The lasar readers for the universal pricing code in some supermarkets is an example of a hard function. The ability of the cashier to successfully scan each item over the reader, however, is an example of a soft function. Another example of a soft function is the consistent loading of sale items on the store computer.

King (1985) also speaks of service quality in terms of its <u>primary</u> and <u>secondary</u> services. The <u>primary services</u> are those the customer pays to receive. In a restaurant the customer pays for a meal that is hot and freshly cooked. If the restaurant advertises live music to accompany the meal, that also becomes part of the primary service because it is part of the customer's expectation. If live music is not available, the customer will reason that he did not get what he paid for. <u>Secondary services</u> refer to things like promptness and courtesy. These elements are not necessarily part of a customer's expectations and it is more difficult to establish a satisfactory performance level. Consider timeliness. When a customer brings his car

in for a brake job and it is finished in half an hour, he may suspect that he was not getting what he paid for. On the other hand, if the car stays in the shop all day, the customer would also be dissatisfied because the service was not prompt enough.

The establishment of a satisfactory level of courtesy is also a difficult matter to resolve. Some customers may prefer a waitress who engages in conversation while she serves, and others may prefer to engage in their own conversations with as little interruption from the waitress as necessary. In the case of courtesy it is easier to measure when it is not present. There does exist a fairly distinct line between rude and courteous behavior, but beyond that any attempt to distinguish between various amounts of courtesy is almost futile. If the customer is not satisfied with the primary services, no amount of effort on the secondary services can make up for it.

King (1985) also adds human behavior as a quality characteristic. Elements of human behavior that influence service quality include human presence (warmth), assurance (security), response (which is idiosyncratic, unstructured, and subject to infinite variations), human dexterity, and human reasoning.

Juran (1975) has identified five major categories of service qualities as viewed from their effect on the users: 1. Internal qualities that are not evident to the user. 2. "Hardware" qualities that are evident to the user. 3. "Software" qualities that are evident to the user. 4. Time, or promptness of service. 5. Psychological qualities. Melan (1987) identifies three key characteristics of service quality: 1. Meeting customer requirements such as timeliness, cost, communications, and accuracy of analysis. 2. Providing a value-add

service. 3. The existance of a feedback-corrective action loop. Folz and Lyons (1986) characterize the concept of quality in municipal services as being related to effectiveness; but more specifically to service level, timeliness, convenience, accuracy, and responsiveness.

As mentioned earlier, there is an element of service quality associated with most products. Thompson, DeSouza, and Gale (1985) identified a number of these service quality attributes. One is product delivery and the related performance characteristics of required lead time, delivery reliability, and product availability. Other attributes include warranty; repair and maintenance availability, response time, effectiveness, and the availability of spare parts; sales service including frequency and caliber of contacts; the company's viability in relation to financial condition and business commitment; advertising and promotional material for the retailer; customization; technical support; the convenience and ambiance of the location; complaint handling; order and billing simplicity; and communicating order status and product development information.

Many technical definitions of quality have been developed. Some of them reflect the unique characteristics of a single industry, but most are general in nature. A large number of such definitions exist reflecting the lack of agreement in the business community in regard to quality. The following selections illustrate the diversity of definitions being used today.

<u>Conformance to Specifications Versus Consistency of Performance</u>

In a manufacturing setting the traditional definition of quality is <u>conformance to specification limits</u> (see, for example, Scherkenback 1985; Thompson, DeSouza and Gale 1985; Zimmerman 1985; Juran 1975;

Scanlon and Hagan 1983a.) The Paul Revere Life Insurance Companies have adopted this type of definition for their insurance operations. They define quality as consisting of two independent parts--quality in fact and quality in perception. The first consists of meeting internal specifications; and the second, meeting the customers' expectations (Townsend 1985). The Hartford Insurance Group has a similar definition in its quality policy: "to perform each job or service in exact accordance with existing job requirements or standards" (Scanlon and Hagan 1983a). These definitions say, in effect, that quality is only achieved when the product or service looks and performs exactly the way the instructions said it would; and, if this is true, no further improvement is necessary or even wanted. This definition will not lead to concurrent improvements in quality and productivity, nor will it stimulate never-ending quality improvement efforts.

A variation of this definition is that quality is <u>meeting customer</u> expectations (Lewis and Booms 1983). This version is expressed in Sheraton's statement of their quality improvement program. Mellin (1977) says, "The efforts of this program are geared toward making certain we give our guests what we promise." Roger G. Langevin (1977), when he was second vice president with The Chase Manhattan Bank put it this way, that quality is the degree to which the product or service satisfies the customer. Hershauer's (1980) definition is more elaborate. He says quality is "the degree to which a product or service conforms to a set of predetermined standards related to the characteristics that determine its value in the market place and its performance of the function for which it was designed."

Another traditional definition of quality is _fitness for use_ (Juran and Gryna 1980). Lewis and Booms (1983) have used this idea when writing about the marketing aspects of service quality. They say that the quality of service depends on the fitness for the purpose of the user. Others equate quality to slogans such as "zero defects" or "do it right the first time."

When 394 hotel operators were asked to define quality, a variety of replies were received. Thirty-four percent described good quality as either the best, finest, or most of something. Twenty percent defined it in terms of the price/value relationship. Fourteen percent equated quality with uniqueness, and eleven percent simply stated that quality is service. Seven percent admitted that they did not know how to define quality. The remaining nine percent gave the following definition that Lewis and Booms (1983) considered to be correct: "The _consistent_ delivery of acceptable standards where these standards are defined as the standards which management deems acceptable in light of the target market and which represent the service to be made available to the customer."

The definition of quality at American Airlines is given by William E. Crosby, Vice President of passenger service: "Service quality is doing _consistently_ well those hundreds--even thousands--of little things that satisfy our customers and cause them to return." At Americana Hotels service quality is _consistently_ meeting the expectation of the customer (Lewis and Booms 1983).

According to Donald E. Petersen, President of Ford Motor Company, a new definition of quality has recently been put in place at Ford. He says that "controlling and _reducing the variability_ of business

processes, in addition to manufacturing processes, is vital to our future competitiveness." Therefore, the new operational definition of quality at Ford is to reduce variability in everything they do (Scherkenbach 1985). The Hartford Insurance Group and ITT have recently adopted a similar definition of quality (Scanlon and Hagen 1983a). They define unsatisfactory quality as "undesirable results due to unwanted and unnecessary variations in performance." Sullivan (1984) says that a new definition of product quality is uniformity around the design dimension rather than conformance to the engineering specification limits. Dimensional specification limits have nothing to do with quality according to W. Edwards Deming (1982). Sullivan (1984) goes on to say, "In the U.S., quality should have as an operational definition that it is a means of reducing waste and therefore of improving productivity. In other words, quality cannot be the end objective; rather, it is a way of lowering manufacturing costs."

Notice that there is a marked distinction between these last few definitions of quality and all the others. The earlier group of definitions all referred to either meeting specifications or the customers expectations. The latter group of definitions are remarkably similar to the Taguchi definition given earlier. These definitions speak of reducing the variability of performance and deliberately avoid all reference to specification limits or standards, and there is a very sound reason for doing this. This reasoning is grounded in Taguchi's quality philosophy.

Taguchi's Quality Philosophy

This will be illustrated using an example from Sullivan (1984) which is in manufacturing terms. The main points of this example will

then be translated into non-manufacturing terms. Figure 1 illustrates the output of three different processes. The horizontal axis represents the measurement of the dimension of a certain part, say the diameter of a piston. The target is the ideal dimension as determined by the design engineers, and the upper and lower specification limits (USL and LSL, respectively) represent the variation in this dimension that the engineers considered acceptable. The area under the curve between any two points on the horizontal axis represents the likelihood that a part produced by the process will fall between those two measurements.

Process I is producing most of its parts on the target value but there is a lot of variability in the process and some parts are above the upper specification limit and others are below the lower specification limit. Process II has less variability but is producing most of its parts between the lower specification limit and the target. While some parts are below the lower specification limit it is very unlikely that the process will produce a part that is above the upper specification limit. Process III shows very little process variation. In other words, the process appears to be very stable. Most of its output measures near the lower specification limit but the likelihood of a part being out of the specification limits on either side is quite low.

Using the traditional definition of quality--conformance to specifications--the output from Process I would be selected as the worst because there is a high probability of finding parts that are out of specifications. The output from Process III would be selected as the best because virtually all the parts would be within specifications.

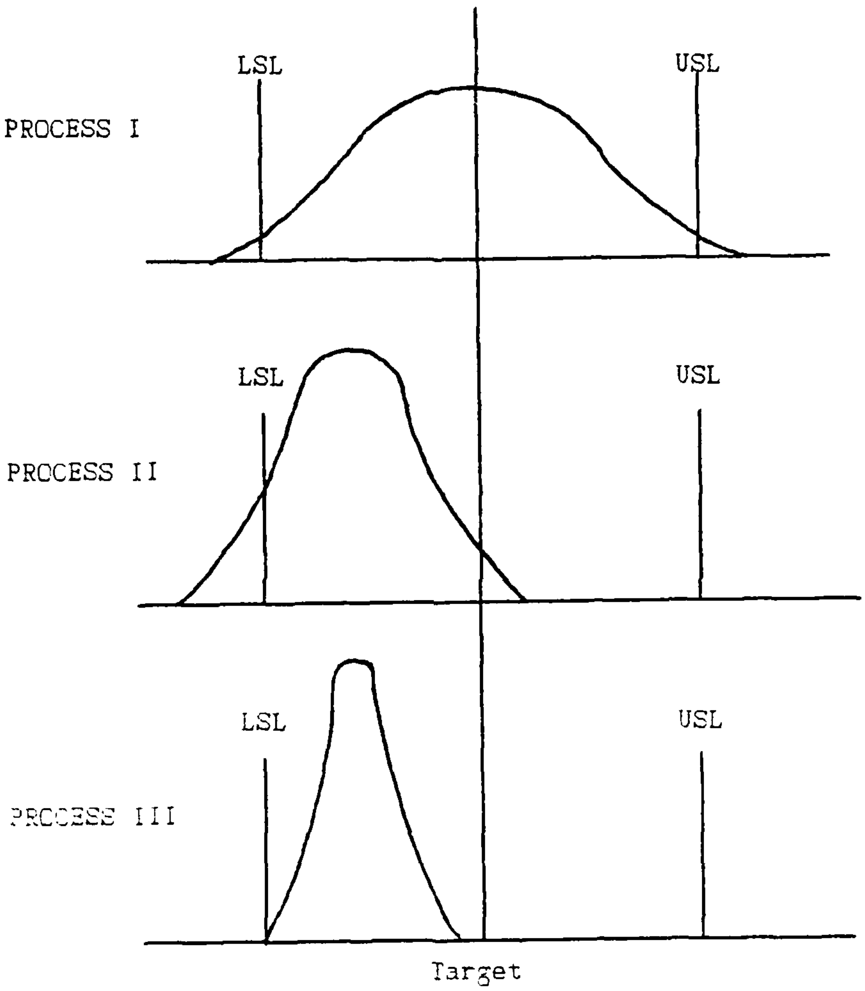


Figure 1
Examples of Process Variation

Based on Taguchi's definition of quality, however, Process I would be selected as the best because more of its output is near the desired target value and Process III would be the worst because virtually none of its output is near the target value.

It might be argued that Process III is the best process because it has the smallest variability and this is the aim of quality improvement--to reduce process variability. This, however, ignores one important element of the correct definition of quality--that it is the variability around the target value that needs to be reduced. If Process III were centered on the target value it would be the best process by far. These three examples were selected to illustrate that mere conformance to specification is not acceptable. Consider the output of Process III again. There is little difference between the majority of the parts produced by Process III and parts that are below the lower specification limit.

The use of the traditional definition of quality is reinforced by the behavior of manufacturers when they write a contract for a vendor to supply them with a certain component. The contract will usually include that the dimensions of the part must fall within the given engineering specification limits. The vendor manufactures the parts in lot quantities, inspects a sample of the lot using published acceptance sampling criteria, and if the fraction defective is low enough the lot is shipped. If this measurement is too high the vendor can be reasonably certain that the buyer will not accept the parts. So the vendor has the option of either sorting out the defective parts in order to lower the number of defectives, or he could sell the lot at a reduced price to someone else, or he could scrap the entire lot.

In an environment like this there is no motivation for the manufacturer to seek process improvement as long as the process output is below the fraction defective limit, even if it means that parts produced closer to the target dimension are of higher quality. Taguchi quantified this value in his well known loss function, and adequately demonstrated that continuing reduction in process variability results in increased profit for the company and a reduction in loss experienced by society as a whole.

How does all this relate to non-manufacturing activities? The concepts of target dimension, specification limits, process variation, and process adjustment are all foreign to service industries. In the first place the output of a non-manufacturing activity can rarely be measured using variable type data as manufactured parts are; that is, in length, weight, hardness, etc. It is also much more difficult to adjust a non-manufacturing process. The adjustment of a manufacturing process may be as simple as turning a dial on a machine. The adjustment of a non-manufacturing process often involves a change in operating procedure and additional training for the employees.

The buyer of services does not write specifications as the buyer of a manufactured item does (Rosander 1985). The desires and expectations of the customer are analogous to product specifications, but it is difficult to put this in numerical terms. If the performance characteristic is response time it may be necessary for the company to select a response time limit that it deems reasonable and then observe the customers' reactions. In this case the target value would be zero, immediate response; and the only meaningful specification limit would be on the upper side of the target.

Sometimes this upper limit may be set by regulation and not subject to customer satisfaction. For example, an Air Force civil engineering squadron has a certain period of time to repair an emergency situation. This time limit is set by regulation and customer satisfaction has little influence on it. In a commercial enterprise, however, if the customer is not satisfied with the response he will simply take his business elsewhere.

In many cases the customer's expectation is that no errors be committed. In this case the target value is zero with zero acceptable variance. There are two ways of responding to this type of specification. Langevin (1977), in describing quality control activities in a bank where it is critical that no errors are committed, reasoned that it was the manager's duty to identify and contain all errors before they escaped his realm of responsibility. This is analogous to insuring that all products fall within specification limits without regard to process variability or centering on target. This illustrates the detection/reaction mode of management that is so prevalent in service industries. Its focus is on containing and correcting the errors.

The second way to respond is to concentrate on the process that produced the errors, and identify and remove the causes of those errors. This means adjusting the process to reduce its variability and center it closer to the ideal target of zero errors. This type of response is known as the prevention/control mode of management. When operating in this mode effort is directed toward continuing quality and productivity improvement through the control of the process variability.

Product Orientation Versus Process Orientation

The traditional view of quality--conformance to specifications--can be characterized by a product orientation. The Taguchi view of quality--reduction in process variation--can be characterized by a process orientation. In a product orientation to quality, the focus of inspection is on the product and its aim is to determine if the product is good or bad. The product is being controlled without regard to the behavior of the process. Efforts to improve the quality of the output are directed toward reducing the number of parts that do not fall within the specification limits.

There are two classes of measurements that can be made of a process. As mentioned in the previous paragraph, process measurements are selected to reveal key characteristics of the process behavior. These measurements usually coincide with key dimensions of the product in most manufacturing situations, but this is not necessary. In fact, in most non-manufacturing situations this is not the case. When process behavior is measured using key measurements of the final product, process performance measurements are used. This is best understood in a continuous manufacturing context, such as the blending of household paint. The output is a paint with a certain chemical composition. Process performance measurements would include a chemical analysis of the product, its viscosity, and its color. When process behavior is measured using measurements that are not directly related to the final product, process state measurements are used. In the paint example, process state measurements would include the flow rate of various component fluids, fluid temperature, and mixing chamber pressure.

Gunter (1987) summarizes Taguchi's approach to quality in two fundamental concepts. The first fundamental concept is that quality losses must be defined in terms of deviations from the desired value rather than conformance to engineering specifications; and that this loss must be measured by the cost incurred by the entire society and not just at the point of defect detection. Taguchi's definition of quality clearly demonstrates the customer orientation that he places on quality. This is in contrast to a producer orientation to quality that only considers the cost of scrap, rework, and warranty and repair costs. The second fundamental concept is that quality has to be designed into the product, not inspected into the product. Taguchi then gives three design stages: systems design, parameter design, and tolerance design.

Gunter (1987) illustrates Taguchi's loss function using the diagram shown in Figure 2. The horizontal axis is the parameter value and the vertical axis indicates the value that is lost. The target value for the parameter is marked in the center with a T, and the upper and lower specification limits are symmetrical about the target and are marked with USL and LSL, respectively. The solid line graph indicates the traditional understanding of quality loss. As long as the parameter value is within the upper and lower specification limits, no value is lost. As soon as the parameter value exceeds either of the specification limits, however, one hundred percent of the product value is lost. The parabolic dashed-line graph represents the way Taguchi understands quality loss. The shape of this loss function is usually difficult to impossible to determine yet it illustrates a very important point--that any deviation from the target

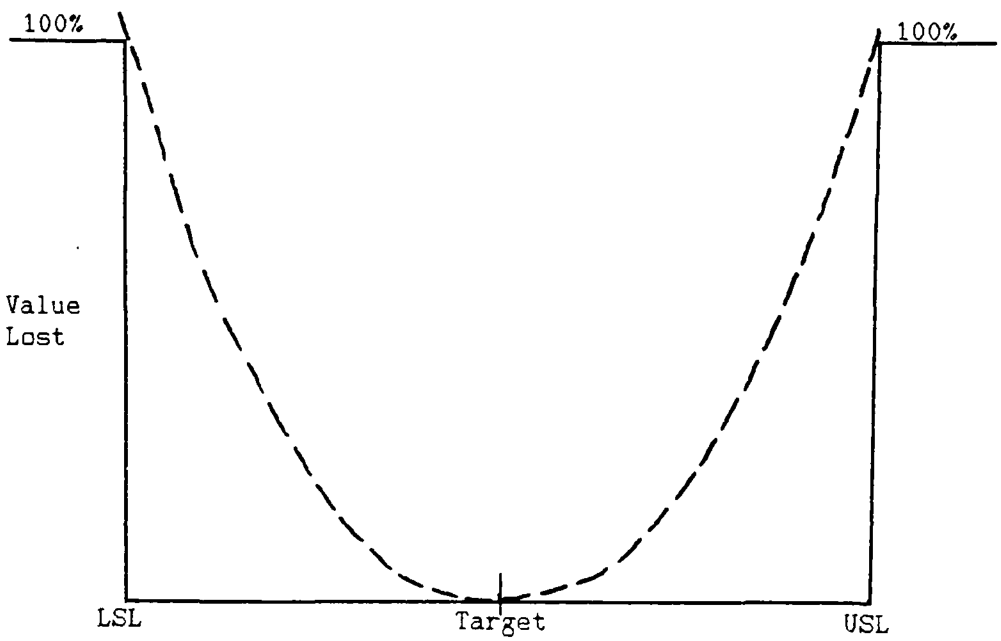


Figure 2
The Taguchi Loss Function

value will result in a loss in product value, and that this loss grows rapidly as the parameter value moves away from the target value.

It is obvious that these two contrasting views of quality have a dramatic effect on management and employee behavior. The work environment under the traditional approach to quality can be characterized by problem solving behavior that is triggered by increasing defect rates or some other undesirable event, and is usually an endless sequence of "fire fights." If there are no trigger events, management and employees are quite content and no effort is taken to do anything to change or improve the process. The work environment under Taguchi's approach to quality, however, can be characterized by problem solving behavior that is triggered by changes in process control charts. If the process is unusually unstable, this problem solving behavior may be quite frantic at first. But as various causes of process variation are identified and removed the pace begins to slow, and more resources are available for process improvement efforts. If there are no trigger events, management will continue to experiment with the process in order to identify and remove additional causes of variation.

Summary

In summary, a good definition of quality emphasizes process control rather than product control. It stimulates never-ending improvement efforts by promoting the prevention/control mode of management rather than the detection/reaction mode of management. The main characteristic of a good definition of quality is its recognition of the necessity to reduce process variability rather than reduce the number of detectives--consistency of performance versus comformance to speci-

fications. Product quality consists of product species, product function, and certain product service attributes. Analogous aspects of service quality include service level and service performance. Service quality can also be characterized by a readiness to serve, hard functions and soft functions, and primary and secondary services. The Taguchi loss function illustrates the economic incentive to pursue never-ending quality and productivity improvement.

CHAPTER 3
The Quality/Productivity Relationship

An increase in service quality causes an increase in operational productivity. This concept is crucial to the survival of any business enterprise, and it is counter to the intuitive understanding most people have of the relationship between quality and productivity. The sole purpose of this chapter is to provide irrefutable evidence of the validity of this idea. It is not merely the idea that quality and productivity can increase concurrently; it is also the fact that an increase in productivity can be the natural result of successful efforts to increase quality as long as quality is defined in an appropriate manner and an appropriate improvement methodology is employed.

Quality is one of the foremost concerns on the minds of consumers today, and this makes it a major concern of business managers. This fact is reflected in the use of the quality idea in many advertisements. Consider, for example, the following statement from a commercial for the Bank Appoaline: "Quality service that you wouldn't expect from a bank this personal." Consider also the claim by Regis Salons, "We listen before we cut." Consumers are looking for service that is done right the first time, and service companies know they must deliver in order to remain competitive. The question remains: how can this be done without damaging the status of the business in other areas?

In today's highly competitive market, a service manager cannot afford to jeopardize his overall position for the sake of quality alone, even if improved quality offers the promise of a growing customer base. He must also be concerned about profits if his firm is to

survive. He must know how to manipulate quality and productivity as well as time and cost in his effort to maximize profits. The typical approach is to treat time and cost as independent variables and quality and productivity as the dependent variables. An increase in productivity may be achieved by investing in faster production equipment or by merely urging the operators to work faster. The first action results in increased cost and the second action may result in decreased quality. Each of these outcomes is anticipated, and the manager weighs the expected profit against the increased cost and the effects of lower quality. On the other hand, an increase in quality may be achieved by purchasing more accurate equipment, by increasing output inspection, or by urging the operators to work slower and more carefully. All three actions will result in increased cost and decreased productivity. These are also expected as necessary costs for improving quality.

The typical manager limits his control over these four variables to time and cost. What is not generally known is that a manager's philosophical bent toward quality and productivity will allow him to treat these two as independent variables as well. This idea will be given more consideration later, but first an answer to the following question will be developed. What can a service manager do to improve the competitive position of his company?

Typical Efforts to Improve Competitive Position

In general, a service operation can be thought of as transforming information just as a factory transforms raw materials. The information comes into the system from the customer. It may be as simple as making a deposit in a savings account or as complicated as a request

for a multi-million dollar advertising campaign. The information enters the system and is transformed through the conversion process until it results in the desired output. In the case of the savings account deposit, the customer's expectation is simple and well defined, and the bank is confident in its ability to deliver. All the customer wants to see is the correct increase in his account balance. In the case of the ad campaign, however, the customer's expectations will be less well defined and the advertising agency will have some doubt as to whether it can satisfy the customer. The customer may expect a permanent increase in his market share but only receive a temporary increase in sales.

Continuing with the savings account example, the input or raw material for the bank's processing system is the information on the customer's deposit slip. The deposit slip should contain all the information necessary to complete the transaction and this information should be correct. The bank has very little direct control over how well the customer fills out his deposit slip. One way the bank can control the quality of this information is by verifying it with the customer prior to completing the transaction. This is an inspection of incoming raw material and always damages productivity. A bank, or any other service operation, has little hope of improving its competitive position through this type of improvement effort. A better way to improve the quality of incoming information is by improving the deposit slip itself and/or providing better instructional aids for the customer in a effort to prevent input errors from occuring. The emphasis on prevention is the key to achieving significant improvements in competitive position.

Capital investments in advanced processing equipment are always prompted by competitive pressures. This is just as true in service businesses as it is in manufacturing. The difficulty with this approach to improving competitive position is that it is only temporary. The advanced equipment is equally available to all competitors. Once the initial risk has been taken by one business and the competition observes the competitive advantage, they would be foolish not to follow suit. It is evident that the mere acquisition of new equipment is also not a means to achieve competitive advantage. What distinguishes one business from another in the area of competitive position is the manner in which they use their available equipment. Deming (1982) asserted that too many businesses consider acquiring new equipment without first realizing the full potential of their existing equipment. Statistical process control is the tool that enables equipment to be employed to its full advantage.

Every business enterprise has a fixed amount of time with which to work. In a capital intensive industry it is desirable in many cases to use all the time available; work three shifts a day, seven days a week. In service operations the time available for profitable work is determined by customer demand. A bank may attempt to improve its competitive position by using its time differently than other banks. For example, the Marine American National Bank in Champaign, Illinois offers service from 7:00 AM to midnight, seven days a week. If they have judged the market correctly, this move will improve their competitive position. But, again, this is only a temporary, static improvement in competitive position. Other banks can follow suit if they see a substantial shift in customer demand. Like equipment, it

is the ability of a business achieves the full potential of the time available to it that determines the strength of its competitive position.

Another resource available to managers is people. It is to a manager's advantage to have the best people possible. One way to attract high quality people is to offer a better salary than the competitors. This is analogous to purchasing more sophisticated processing equipment. An excellent training program is another way to ensure that the people are the best qualified to do the job. This, however, is also the goal of each of the competitors. Although a company's effectiveness in acquiring and retaining high quality people will have a considerable impact on competitive position, this too may only be temporary.

What avenue, then, is available to a manager that will ensure a continuing competitive advantage for his company? The answer to this question lies in a correct understanding of quality and how it is achieved through the use of statistical process control techniques.

Quality control has long been associated with product manufacturing. The products usually take the form of material goods. The manufacturing processes involved include metal casting and cutting, welding, assembly, inspection, and testing. Quality criteria come from the part blueprint in the form of dimension tolerances or test specifications. Part quality is measured in terms of defects, functional failures, and dimensions that fall outside specifications. All of the quality control textbooks are written to a manufacturing audience using manufacturing examples. With the increasing concern for quality in the service sector, service managers naturally turn to their manu-

facturing counterparts to see now they are managing quality. What they see, in the vast majority of cases, is product oriented control. Product control reflects the traditional philosophy of quality and has a direct impact on how the four major variables in a conversion process (quality, productivity, cost, and time) interact with each other.

This chapter is concerned with the relationship between quality and productivity. It is easy to see how time and cost must be manipulated in order to increase productivity, so this topic will remain untouched. What is not so easy to see is how quality must be manipulated in order to increase productivity. This is due to the prevalence of product control in manufacturing.

Product Control

Product control is characterized by defect detection and containment. It frequently employs 100% inspection of the process output to ensure that no errors are passed on to the customer. Product control is mainly concerned about the product characteristics being within specified tolerances. It classifies a part "good" if its dimensions fall within tolerances or if the number of defects are below the maximum allowable. A part is labeled "bad" if it does not comply with specifications. The system plans for a certain amount of scrap and rework. Records are kept on scrap and rework rates. If these rates get too high, top management gets concerned and starts motivating the production manager to do something about them.

It is easy to see from this brief description of product control just what impact it has on productivity. In order to maintain an acceptable level of outgoing quality, considerable effort must be applied to the inspection process. This effort is nonproductive.

Rework is also nonproductive because its efforts are expended on something that should have been done right the first time. Scrap is simply throwing part of the production effort away. All three of these activities reduce the organization's productivity, but they are all considered necessary for the sake of quality when considered from a product control point of view.

Consider, for example, the production of notebook paper. Dark pieces of fiber occasionally occur as blemishes in the paper. The company may decide to sell two grades of paper. The low quality paper will sell at a reduced price because they will not bother to sort out the blemished sheets. The high quality paper will cost more because of the extra expense involved in detecting and containing the blemished sheets before they are packaged. It is this kind of reasoning that leads obviously to the conclusion that quality always costs more, and this thinking is still largely accepted by consumers. They are willing to pay more for quality. Consider the competitive advantage a company would have if it could provide superior quality at less cost.

Service managers also take note of the various initiatives taken by manufacturing companies to improve productivity. Frequently these initiatives take the form of capital investment in higher capacity machinery or more sophisticated automation. The use of work standards and production quotas are also efforts by manufacturing to increase the productivity of their work force. A recent improvement in productivity enhancement involves the use of quality circles or some other worker participation program. These efforts may give promising results but are not nearly as effective as quality improvement through the use of statistical process control. W. Edwards Deming (1982) says

that specifications and work standards are, in fact, a detriment to quality and productivity. Mr. Zimmerman (1985), vice president of United States Fidelity and Guaranty Company in Baltimore, offers the following promise to companies that pursue quality improvements through statistical process control. "The opportunities for cost-effective implementation of quality efforts are like a great unexplored frontier. The companies that are going to make the greatest headway from a productivity standpoint are those that explore and expand their present horizons to accomodate improvement in goods and services so that quality becomes an integral part of all phases of the service industry operation."

Following the example of their manufacturing counterparts, service managers attempted to apply product control to their operations. Many concluded that their operations were so different from manufacturing that quality control techniques simply could not work. They remained content to continue running their businesses on intuition and experience. Roger G. Langevin (1977), executive in charge of the Quality Control Division of The Chase Manhattan Bank, came to this conclusion in 1977. He said, "The concept of zero-defects, which grew out of the highly reliable aerospace programs, cannot be applied to the clerical operations typical of those in most service industries."

The idea that service operations are different is still being espoused. Carol A. King (1985), president of the Qualityservice Group in Princeton, New Jersey, said that the techniques used in manufacturing to measure conformance to a standard must be modified before they can be applied to service operations. She went on to say that industrial techniques of inspecting and testing are only partially helpful

in measuring conformance to service standards. Others say that final quality cannot be insured by inspection since the service is consumed as it is being provided (Thompson, DeSouza, and Gale 1985).

Notice the product orientation of these statements. Carol King sees quality control efforts as comparing the output with specified standards. The idea that output should be inspected prior to delivery to the customer is definitely product control. The object for these quality programs is to identify and contain errors before they get to the customer. Langevin (1977) goes so far as to state this explicitly. He says that quality control is detecting and correcting errors before the product leaves your span of control.

In spite of the difficulties involved in applying product control, some companies have done so and consider their efforts effective quality control. The program at the Consumer Goods Distribution Center of the Fram Corporation in East Providence, Rhode Island is just such a program (Martin 1985). The distribution center was concerned about the number of line items in error on orders shipped from their warehouses. They inspected a random portion of filled orders before they were loaded on the truck in order to make sure the items contained in the crate matched the items listed on the packing list. When they found an error they sent it back to the responsible worker for correction. This was their corrective action plan. They monitored each work group's performance with p-charts. The ultimate goal was to force the error rate down by periodically lowering the goal as each group showed improvement. They did realize some improvement using this technique, but it was due solely to the operators increasing their attention to detail. Although this is important, their approach

to quality control did not help them find other causes for error and additional opportunities for improvement. Their goal was to reduce the line item errors on outgoing shipments to 0.5%. With the correct understanding of quality they would see the logic of striving for zero errors. A similar program is in place at the Materials Handling Parts Distribution Center operated by the Eaton Corporation (Janas 1976).

A service operation is obviously different than a manufacturing operation, but certain analogies can be made that help relate the two processes. The product of a service operation is the effort put into doing something for the customer. It may be the compiling of a monthly checking account statement, a hair cut, or a set of recommendations to solve a technical problem. The processes include administrative, clerical, and the mental processing of information. The quality criteria can be defined as the errors to be avoided, response time, or customer turnover.

It is unfortunate that the quality control programs of manufacturing proved to be such poor examples. Service industries were in the position to start their quality improvement programs with the correct philosophy. Since it is very difficult, if not impossible, to inspect the final product before it is delivered to the customer, service industries could have avoided the trap of product control with its error detection and containment approach to management. Most service industries by now have experienced product oriented quality programs, so they are in the same position as most manufacturing industries, because most American manufacturers still have not realized the error in their quality philosophy. They both have to change the quality philosophy of their organizations. To do this, it requires

relentless, long term effort by the top manager in the organization. The top manager must change his philosophy first, then make sure everyone else, all the way down to the janitors and temporary office help, change theirs. The correct understanding of quality is what causes productivity to increase with each successful effort to improve quality.

Statistical Process Control

The correct understanding of quality does not associate quality with conformance to specifications. It avoids 100% inspection of the final product. The correct understanding of quality is contained in the approach to quality control called statistical process control. The effort is not applied directly to the control of output quality, but it is applied to the control of the process. It does not matter what kind of process it is or what kind of errors the process can produce. Statistical process control is applicable to all processes: typing, answering the telephone, responding to customer complaints, turning the diameter on an engine bearing surface, assembling electronic components on a printed circuit board, delivering office mail, and so on. Statistical process control provides vital information about the process performance. Out-of-control signals on the process control chart indicate unnatural variation in the process. The cause of this variation is called a special cause because it is only present occasionally. Special causes are relatively easy to identify because the process control charts provide a rough indication of when the event occurred. Once a special cause is identified corrective action can be taken to remove it from the process. Special causes are not part of the processing system. They are imposed from outside the

system and it is generally within the power of the individual worker or immediate supervisor to take corrective action. According to W. Edwards Deming (1982), fifteen percent of process variation is due to special causes. Each cause of variation removed from the process will decrease the chance of producing undesirable output. A process that is in statistical control has the potential to produce higher quality output than when it is not in statistical control because no special causes of variation are present to increase the variability of the process. More will be said about causes of variation in the next chapter.

Once all special causes of variation are removed, the process control chart will show that the process is running in statistical control. This does not mean, however, that the process is producing 100% acceptable output. It just means that the process is operating under a constant system of <u>common causes</u> of variation. The source of this variation comes from what is called common causes. Common causes of variation effect the process continually in the same manner. These causes are more difficult to detect because the control charts cannot indicate when and where to look. However, once a common cause is identified and removed, the control chart serves to verify and maintain the corrective action. Effective corrective action will appear as an out-of-control point on the control chart in the direction of process improvement. This improvement is maintained by recalculating the chart control limits and operating the process at its improved performance level. There are many techniques available that help identify common causes of variation. They all come under the heading of problem solving techniques and intimate experience with the process

is always helpful. Some of these techniques will be discussed in the next chapter.

Common causes of variation are part of the processing system itself. Deming (1982) estimates that 85% of the variation in a process is due to common causes. Even if the operator or supervisor knew about the problem, they would be powerless to do anything about it because a fundamental change in the system is usually required to eliminate a common cause of variation. The workers are only able to function within the system as it is provided to them by management, and they can only be held responsible over that which they have control. The workers do not have control over the design of the system. They cannot change operating procedures or regulatory requirements. Only management is able to do work on the system that will result in the removal of common causes of variation.

For every cause of variation removed from the process, whether it be a special cause or common cause, the quality of the output will increase. The examples that follow will illustrate that a concurrent increase in productivity is also realized because every cause of process variation is also a source of waste and inefficiency. Once a manager is convinced of this fact he will be motivated to continue process improvement even after the output is totally satisfactory. A sufficient decrease in process variability will also cause additional savings. It will eliminate the need for all final inspection of the output, rework due to errors, and scrap. The only inspection required will be what is necessary to maintain the process control charts; and as performance improves, even this sampling frequency will decrease.

The definition of quality developed in the previous chapter establishes the ground work for quality improvement and process improvement activities. The following examples will show how statistical process control has been applied in companies that have the correct understanding of quality, and how they have experienced a concurrent improvement in both quality and productivity. Both a manufacturing and a non-manufacturing example will be used to make this point clear.

Case Studies: Quality and Productivity Improvement via SPC

The first example is taken from Sullivan (1984). When making an assembly from a number of separate parts, tolerance stack-up is always a concern. If a company is operating under the "conformance to specifications" definition of quality, parts will be produced over the entire range from the lower specification limit to the upper specification limit, and a disproportionate number of parts will fall just inside the limits due to rework activities that catch and repair nonconforming parts. Tolerance stack-up recognizes the fact that parts just inside the lower specification limit will not fit properly with mating parts produced just inside the upper specification limit. Tolerance stack-up was especially evident at Ford in their door fitting operation. It was common operating procedure to have a door fitter on the assembly line adjust hinges, bend door frames, and shim weather strips to achieve the proper fit. This was an expensive operation requiring a skilled operator, since the door fitting actions for each car were unique.

If each of the components were produced near the designed target value with little variation there would be no tolerance stack-up pro-

blem and the door fitting operation could be eliminated. Statistical process control was applied to the production process of each of the component parts and Ford was able to reduce the variability to such a degree that they have eliminated the door fitting operation and realized a considerable savings in production costs (Sullivan 1984).

The second example is taken from Baker and Artinian (1985). Ford operates an export supply company out of Ontario, Canada called Windsor Export Supply. In this operation the crating and shipping services are performed under contract by other companies. Windsor Export Supply was experiencing an increase in the number of freight bills that were rejected for payment by their audit system. In addition, several of the shipping companies were becoming dissatisfied with excessive delays in receiving payment. Some of the shippers even threatened to not accept any more work if the situation was not improved.

A project team was assembled to solve this problem and their first action was to diagram the bill processing system. With this understanding of the system they developed three objectives: reduce the time taken to pay the shippers, reduce the number of phone conversations with the shippers concerning overdue payments, and reduce the time taken to audit and correct payments to shippers.

It was possible to monitor the process using a number of different measurements. Each set of producer-user interfaces could be analyzed using statistical process control. They decided to use the number of days elapsing between the date an invoice was received by the Windsor Export Supply traffic office and the date the payment check

was issued by the accounts payable office. They selected this measurement initially because the data was easily obtainable.

The effects of process improvement efforts are shown in the process control charts in Figure 3. The portion of the chart to the left of the vertical line labeled 1 represents the behavior of the process before any corrective action was attempted. This portion of the chart serves as a base-line against which the effects of subsequent actions can be evaluated.

The project team was formed at the point in time represented by line 1. Since the process was in statistical control the team concluded that no special causes of variation were present. The output of the process, however, was unacceptable so they proceeded to search for a significant common cause of variation. With the aid of an Ishikawa cause-and-effect diagram the team was able to analyze several reasons why so many bills were being rejected by their mechanized audit system. These reasons were, keypunch errors including incorrect carrier codes, incorrect dollar amount, and a truncation of the last two digits of the billing number; filing errors; missing carrier/ vendor codes; and lost or misplaced bills.

A major revision of the processing system was required to improve the overall performance. The process performance after the implementation of the new system is shown on the portion of the charts to the right of line 2. Notice that the control chart goes out of control below the lower control limit due to the changes to the system. In this case the new system is a special cause of variation and the out-of-control points verify that it was effective. An ineffective action would not have caused a change in the chart and the team would have to

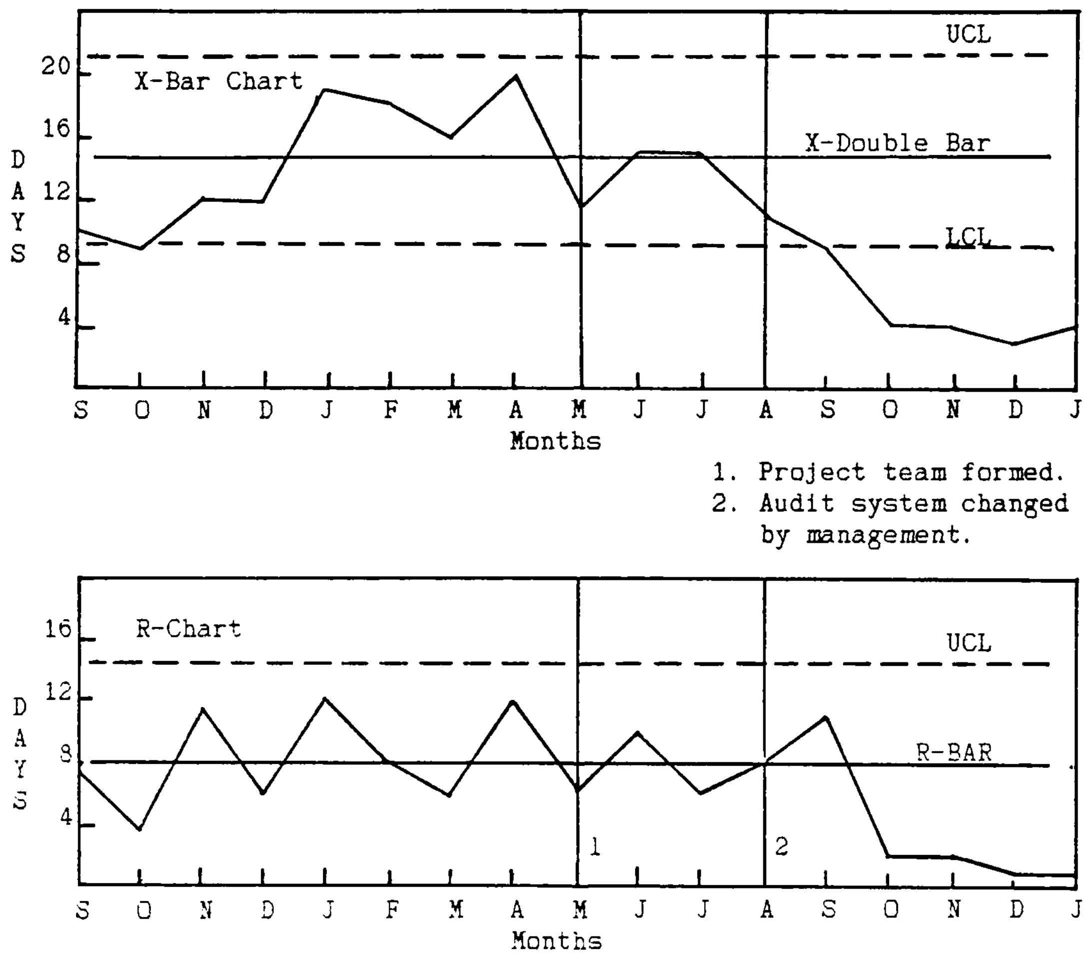


Figure 3
Windsor Export Supply
Freight Audit and Payment System
(Number of days required to process)
(Baker and Artinian 1985)

search for another reason for the high reject rate. The continued use of the chart will insure that the process continues to operate at its improved level. The control limits should be recalculated using the new data so that any tendency to increase the processing duration can be revealed as an out-of-control condition and corrective action taken immediately.

The average number of days required to process a bill was reduced from fifteen days to six with an associated reduction in the variation. The proportion of bills rejected by the system has been reduced from 34% to less than one percent. This was a significant increase in the output quality. In addition, this increase in quality was achieved at the same time as an increase in productivity. As of the time the article was written Windsor Export Supply had not received a query tape from their accounts payable department--an event that occurred frequently and was often several pages in length. Each item on the query tape required at least one phone conversation or a review of microfiche records. Supervisors were spending most of their time determining what went wrong with each rejected bill. They had little time for doing anything else. The elimination of this requirement relieved management of this burden and allowed them to begin managing their operation--a clear example of concurrent increases in quality and productivity.

Notice the change in approach to the problem from detection/reaction to prevention/control. Prior to the change rejected bills were detected by the accounts payable department and sent to the Windsor Export Supply traffic office where the management reacted by personally clearing each of the errors. After the new system was implemented

management was free to concentrate on maintaining control of the system and preventing further causes for rejected bills.

Process Control Feedback Loop

The key to achieving concurrent improvements in quality and productivity is the existance of a process control feedback loop within a production system. This feedback loop has been referred to in many different ways but the best is still the three steps given by Shewhart (1939) in the 1930s--specification, production, and judgment of quality. He says that these three steps "constitute a dynamic scientific process of acquiring knowledge....mass production viewed in this way constitutes a continuing and self-corrective method for making the most efficient use of raw and fabricated materials." This concept is easily related to non-manufacturing activities, or any other activity for that matter, when it is realized that these three steps are analogous to making a scientific hypothesis, conducting an experiment, and then testing the hypothesis.

The hypothesis in the manufacturing sense is that the production process is able to consistently produce a part of a specific dimension within a certain range of accuracy. That is to say that the process is subject only to a constant system of common causes of variation. The experiment is the act of setting the controls of a machine and making a number of parts. The initial hypothesis is tested by measuring the parts produced and judging in a statistical sense whether or not these measurements could belong to a population with its mean at the target dimension and at least six standard deviations of its variation within the allowable specification limits.

It is just a short step in logic to apply this to a non-manufacturing example. A business process is organized for the purpose of administrating a welfare program, and it is hypothesized that this process can insure that all regulations are followed so as not to fall below a specified minimum accuracy rate. The process is put into operation (the experiment) and records are kept on its performance. The hypothesis is tested by extracting error data from the records and judging whether the process output could belong to a statistical population that conforms to the specified accuracy rate.

What is not obvious in the three steps listed by Shewhart is the necessity for corrective action, not only when the hypothesis proves to be false, but also in order to remove special and common causes of variation. Kackar (1986) emphasizes that process specification limits should only be tentative cut-off points used to standardize a process. As the process variability is reduced, the specification limits lose their significance. Only with meaningful corrective action can Shewhart's intention of a "continuing self-corrective method" be realized.

Statistical process control enters this process feedback loop in the third step where the hypothesis is tested. The control chart serves as a continuing statistical test of hypothesis. Every time a point is added to the control chart a comparison is made between the established process performance and the experimental data. Out-of-control conditions signal a departure from the established performance and, in essence, prove the hypothesis false. These signals either trigger corrective action that returns the process to its established performance or indicate that some process change has resulted in sig-

nificant improvement and should be continued. This last event returns the cycle to the specification step where the new process performance level becomes the hypothesis for the next set of experimental data that is collected.

Another way to define the process control feedback loop that recognizes explicitly the requirement for corrective action is through the use of the quality control window concept (Dessouky, Kapoor, and DeVor 1987). Quality control windows are placed at strategic locations within a process for the purpose of process control and quality/productivity improvement. A quality control window has five distinct elements: observation, evaluation, diagnosis, decision, and implementation that form an iterative cycle. The Shewhart control chart is a necessary tool in this cycle. The observation of the process produces data that is evaluated using control charts. Special causes of variation identified by the control charts are diagnosed using various problem solving techniques and a specific corrective action is selected (decision). Finally, the corrective action is implemented and the results of this implementation become new observation data as the cycle continues.

Cost of Quality

The quality/productivity relationship cannot be fully appreciated without a discussion of the cost of quality. There are four essential categories of quality costs (Aubrey and Eldridge (1981). The first is internal failure costs. These costs refer to the activities devoted to correcting defects or errors before the customer has an opportunity to discover them and complain. The second is external failure costs. These costs are incurred by those activities required to correct

errors discovered by the customer. Hidden in external failure costs are those costs related to the loss of dissatisfied customers. The third cost category has to do with the activities related to the appraisal of quality within the system. The fourth category is prevention costs. Prevention costs are incurred by all the activities designed to keep failure and appraisal costs down by taking steps to keep defects and errors from occurring.

Quality activities in most companies concentrate on internal and external failures because these present the most urgent situation to management. Aubrey and Eldridge (1981) discovered that about 50% of their quality costs were due to both internal and external failure. They realized significant improvements in quality and productivity by shifting some of this cost to prevention activities. In order to accomplish this it is necessary to shift attention from what is the most urgent to that which is the most important in the long run. Statistical process control is the tool to accomplish this purpose.

Quality costs are traditionally thought of in terms of how much it costs to achieve and maintain quality. Another set of costs do not typically enter into the equation. These are the costs associated with not having quality. The following example is attributed to DeVor and Chang (1986). Sony compared the color intensity on television sets made at one of their United States factories with sets made at one of their Japanese factories. Virtually none of the sets made in the U.S. had color intensity that measured outside the specification limits yet the distribution of measurements between the specification limits was nearly uniform. In other words, it was just as likely to find a set that measured close to one of the specification limits as

it was to find one that measured right on target. Among the Japanese sets tested, however, a few were found that fell outside the specification limits yet the distribution within the specifications resembled the bell shape of a normal distribution. It was far more likely to find a Japanese set that measured close to the target value than it was to find one near the specification limits.

This example is used to illustrate the fact that the U.S. distribution did not resemble a naturally occurring distribution and this implies that something was done to the U.S. output that was not done to the Japanese output. Whatever this was, it resulted in additional cost. It is this cost that is characterized as the cost of not having quality.

The U.S. factory could be engaged in one of several possible activities that would result in such an unnatural measurement distribution. Detecting and reworking all of the sets that did not meet specifications is one way this could happen. The costs incurred in this activity include excess inspection cost and the cost of rework. In traditional terms these could be considered internal failure costs, but they are the costs associated with not having a process that can be relied on to consistently produce high quality parts--a process with reduced and controlled variability. It is as if the business of achieving quality includes making defective items and making them into good items.

An unnatural distribution of output measurements can also be achieved even if the process has a low level of variability. In this case the process may be allowed to drift from just inside the lower specification to just inside the upper specification before process

adjustments are made. This would result in a uniform distribution of measurements between the two specification limits. Again, an excessive amount of inspection is required to control a process in this manner. In addition, the problem of tolerance stack-up is exacerbated.

Another way an unnatural distribution could be realized is through over control of a well behaved process. Failure to recognize and understand the nature of inherent variation in the process usually results in process adjustments when no adjustment is warranted. The operator incorrectly concludes that an observed shift in process output is due to a drift in the setting rather than due merely to the natural variation on the process. This is over-control and unnecessary costs are associated with it.

With the proper use of statistical process control the costs of not having quality can be avoided and the costs of having quality can be seen as investments in increased productivity.

CHAPTER 4
The Concepts and Techniques of Statistical Process Control

Statistical process control is an essential tool around which all quality/productivity improvement programs should be built. Most of the textbooks and journal articles, however, are directed toward manufacturing applications so the managers of non-manufacturing activities are left to fend for themselves as far as the application of these techniques is concerned. In recent years, several successful applications have been noted in the literature. Managers in all types of companies are showing more and more interest in statistical process control because they are feeling the pressure to improve quality and productivity. The pressure for improved quality is coming from their customers, and the pressure for improved productivity is coming from their competition. Managers of nonprofit organizations and government service operations are also feeling the pressure to improve due to reductions in staff authorizations and operating budgets. This chapter will take the key concepts and techniques of statistical process control and explain them in terms applicable to the non-manufacturing environment.

The Meaning of Statistical Process Control

The meaning of statistical process control can be understood by analyzing each of the three words separately (Pennucci 1983). The term "process" implies that it is the process that is the focus of control, not the product. Pennucci (1983) uses the term in-process rather than merely process to emphasize this fact. It suggests that the variables affecting the quality characteristics important to management are controlled during the manufacturing process. This

approach is in direct contrast to the "make-inspect-sort-rework-scrap" cycle that is an impediment to quality and productivity improvement. Statistical process control is applied at the level of the manufacturing activity, not at the end of the process when all the mistakes have been committed. By emphasizing quality during the production process the responsibility for variable control (quality) can be placed on the operators of the process, because they are in the best position to collect the process data and analyze it on the spot.

The term "control" is defined in a statistical sense. It is the control of the average of a product or process characteristic. The control of this average is maintained within statistically defined variability limits which are calculated using the standard deviation. Control implies that each time this average is calculated the same data population is used. This means that no statistical evidence exists that would lead someone to suspect that one calculated average was significantly different from the next. In order for this to be true, the process that made the parts would have to be subject to a constant system of common causes of variation. This idea will be extended later in this chapter.

The implications of this control are far-reaching. It is valuable in a manufacturing environment to be able to make valid predictions about part quality. Predictions need to be made about the quality of parts that have been made and inspected, about parts that have been made yet not inspected, and about parts that have not yet been made. These predictions can be made with confidence only when the system is in control in a statistical sense. Pitt (1985) says that

the only way to ascertain that a process is in statistical control is through the use of control charts.

It is valuable to make similar predictions about non-manufacturing process performance. Consider the problem facing a Pizza Hut executive who has promised to serve a personal pan pizza within five minutes during the lunch rush. He must be confident in his prediction of the performance of the pizza production and delivery system. This confidence must extend to his being able to determine what restrictions he must place on this offer to insure consistent success.

"Statistical" means that the process measurements and control limits are calculated using statistics, i.e., a statistical model for the process data is employed. The measurements are made using either variable or attribute data. The statistical analyses conducted during process control define variations in the measurements as either due to special causes or common causes. Variations due to special causes are detected by statistical instability and statistically significant differences. They result from forces outside the normal operation of the system and can be avoided by taking action at the process. Variations due to common causes are by definition statistically stable. They result from forces that are inherent in the product's design and/or in the manufacturing process, and can be avoided/reduced only by making fundamental changes in the operating system.

<u>Manufacturing Versus Non-Manufacturing Applications</u>

There are four fundamental terms used in a manufacturing context that have significantly different meanings when used in a non-manufacturing context. These are customer, producer, product, and process.

The "make-inspect-sort-rework-scrap" cycle also takes on a different character when used in the non-manufacturing setting.

In manufacturing, the "make-inspect-sort-rework-scrap" cycle can be explained as follows. The production line operates at full capacity making a product. Quality inspectors take a sample of the product and compare selected product characteristics with the design specification limits. If the defect rate is too high, 100% inspection will be required to sort out the defective product. It may be possible to fix some of the defective parts, so they are sent to a rework station where they begin the cycle again. The parts that cannot be fixed are scrapped.

A similar cycle can be identified in non-manufacturing activities even though a tangible product is not always involved. Take the SPEAK-UP! program at IBM for example (McCabe 1985). This program is a means provided by the company for the employee to communicate ideas, suggestions, or grievances to top management. It requires that a reply be written and returned to the employee who originated the communication within a reasonable period of time. The reply is drafted by the functional area manager that is directly responsible for the item under consideration, and then sent to a senior manager for signature. This reply must meet certain criteria and is often returned to the writer for revision. The steps of the cycle are obvious. The functional area manager writing the reply is engaged in a production process, and the letter is the product that must meet certain quality criteria. The senior manager or his secretary inspects the letter to determine if it meets the quality requirements. In this case inspection of the output is one hundred percent. If the letter does not

meet the quality requirements it is sent back to the writer for rework, and the cycle starts over again. In this process it would be a rare event to have the product (the reply letter) scrapped. All requests submitted through the SPEAK-UP! program required a reply. It is much more common to replace or re-assign the individual writing the letter. This is analogous to a manufacturer replacing a milling machine with a newer model.

In some non-manufacturing activities this cycle may not be as obvious, but it is nevertheless present. Consider an employee performance appraisal system (Scherkenbach 1985). Throughout the duration of the appraisal period an employee is working on his performance, hoping to meet the criteria required for an outstanding evaluation. At the same time the supervisor is inspecting the employee's performance. When the evaluation is written at the end of the appraisal period, the product (the employee's performance) is complete; and the supervisor passes judgment on it as to whether it is good or bad. If it is less than outstanding the employee will rework his performance during the next period in a effort to improve. If his performance is less than adequate, he may be given additional training or be re-assigned to a position that better matches his abilities. In the extreme case, the employee is fired if performance does not improve. Providing continuing education for the employee may be compared to equipment maintenance. In this example it is interesting to note that all improvement efforts are concentrated on the processing system (the employee) just as it should be in manufacturing.

Statistical process control and the use of process control charts will break this cycle and replace it with the "data collection-anal-

ysis-feedback-corrective action" cycle that is essential to never-ending improvement efforts. Examples of this will be given later with the discussion on the interpretation of control charts.

<u>The Meaning of the Customer</u>

People ordinarily think of a customer as any one who buys a product or service--the one who pays money for what has been done. The idea of customer must be extended to include anyone to whom a work unit provides products, services, or information (Townsend 1985). Nickell (1985) put it this way, "the recipient of any of your work is your customer both inside and outside the organization." On an assembly line this means that any work station is the customer of the previous work station. In an office the people who receive an internal memo are the customers of the person who wrote the memo. The material purchasing section is the customer of those who place purchase orders, and the employee is the customer of the payroll processing section. Therefore, everyone in any organization is a producer of outputs for an internal or external customer (Hermann and Baker 1985). The distinction between internal and external customers is made only to make the following discussion easier to understand. This discussion makes it clear that the internal customer should be accorded the same consideration that an external customer receives.

The internal customer is often treated as a second-class customer, however. Every organization is well aware of the importance of the external customer and they go to great lengths to ensure customer satisfaction. If the external customer is a large assembly plant, special care is taken to make all parts according to the customer's specifications. If the open market is the external customer, a com-

pany will invest in a market analysis before producing a product. Once a product is in production, the marketing effort will continue in order to insure that the product is meeting the customers' expectations.

The internal customer rarely receives this kind of consideration. It is often the case that the requirements of the internal customer are completely ignored and in some cases even deliberately thwarted. An example of this can be found in a facility maintenance organization. Job planners write purchase requests for required materials. These requests are sent to the material control section which does the purchasing. Frequently the material description is inadequate and this causes difficulty for material control in placing the order with a vendor. There are also occasions when this causes the wrong materials to be ordered. In this situation the internal customer (material control) requires that the product from the planning section (the purchase request) have a complete description of the required materials. This requirement is known by the planners, yet the extra care and effort required sometimes falls victim to a more pressing planning schedule. Writing the purchase requests is usually the last task to be performed, so it is often done in a hurry in an attempt to complete a plan on schedule. This demonstrates a lack of teamwork within the organization and a lack of committment to internal customer requirements.

James E. Olson (1985), president of AT&T, recognizes the importance of teamwork within an organization. He says if one work unit passes on something that is poor quality, the next person or next step in the process is adversely affected. AT&T has been successful in

promoting teamwork among its work units. The Ford Motor Company (Hermann and Baker 1985) has also committed itself to improving teamwork within its operations as a means to improve quality and productivity. They have adopted the same approach to meeting internal customer requirements as they have used to meet their external customer requirements. The first thing they do is to know who the customers are and what their needs are. Secondly, they insure that available resources are managed efficiently in order to meet these needs. And finally, they require that each work unit be creative, innovative, and willing to take risks.

With this expanded understanding of the customer, it is easy to apply it to any situation. Scanlon and Hagan (1983a) describe any enterprise as a network of independent processing systems, each having multiple suppliers of inputs and multiple customers for their outputs. Hermann and Baker (1985) add that every processing system operates both as a producer and as a customer.

Product and Process

In the previous discussion the term product was used in several different contexts because it is closely related to meeting customer needs. With this in mind a product can be defined as anything that meets an internal or external customer's requirements. In manufacturing, the product is physical with easily defined and easily measured characteristics. In service industries the product is often intangible. In fact, in some services such as counseling and advising, the product is the state of mind of the customer (Hochschild 1983). It is more common for the product to be defined as services provided. Exam-

ples of such products and the quality control problems associated with them were presented in Chapter 1 so will not be repeated here.

In manufacturing, the process is obvious. It includes such things as casting, molding, cutting, fastening, and assembling. In service industries the processes are not so obvious. Sometimes the process is as esoteric as the mental processing of information and decision making. More common processes include administrative, clerical, proof reading and verifying, communicating, data processing, and typing. Dmytrow (1985) defines a process as "some unique combination of tools, machines, methods, materials, and men engaged in production." A non-manufacturing process usually does not contain all of these elements. For example, it is possible for the mental processing of information to only involve the human element. The materials consist of intangible ideas. The tools, machines, and methods may all be embodied in the human ability to reason. Melan (1987) identifies three types of processes involved in enterprises that create a product or service: first, physical processes used to manufacture, deliver, and support the product or service; second, informational processes used to plan, develop, manufacture, and deliver a product or service; and third, management processes that determine the structure in which physical and informational processes operate. In manufacturing, the process is adjustable and the products are consistent. In non-manufacturing, however, the process is consistent but each product is often unique (Scanlon 1980). Take the typing of a letter, for example. The process of typing is the same no matter what is being typed. The letters that are the products of the typing process, however, are each distinctly different.

Non-manufacturing products and processes present unique problems for quality control efforts, but the preceding discussion will help to make the following presentation of the specific details of statistical process control easier to understand. A statement recently reiterated by Box and Bisgaard (1987) emphasizes the common nature of these different processes that can be exploited using statistical process control. They say, "Every process generates information that can be used to improve it. This is perhaps simple to see when the process is a machine. But the philosophy applies equally to a hospital ward, to customer billing, to a typing pool, and to a maintenance garage. Every job has a process in it, and every process generates information that can be used to improve it." It is this information that is used by statistical process control.

Another thought worth consideration is that manufacturing processes, in general, are easily adjustable; but non-manufacturing processes are usually very difficult to adjust. A manufacturing process is subject to such forces as tool wear, setting drift, temperature of the work piece, alignment of the fixture, and chips on the fixture. These causes of variation are easily identified with control charts and easily corrected by the operator on the spot. A non-manufacturing activity is not amenable to this kind of treatment so this may suggest that statistical process control and control charts are not of any use. A non-manufacturing process is subject to a different set of forces: inconsistent office operating procedures, poorly maintained office equipment, inadequate instructions and training, mental fatigue, distractions, and attention drift. Levitt (1972) explained the difference between the manufacturing and non-manufacturing

approaches to the process control problem in the following statement: "Manufacturing looks for solutions inside the very tasks to be done. The solution to building a low-priced automobile, for example, derives largely from the nature and composition of the automobile itself. (If the automobile were not an assembly of parts, it could not be manufactured on an assembly line.) By contrast, service looks for solutions in the performer of the task. This is the paralyzing legacy of our inherited attitudes: the solution to improved service is viewed as being dependent on improvements in the skills and attitudes of the performers of that service." He goes on to say that "service thinks humanistically, and that explains its failures."

There is some disagreement among current practitioners of quality control about the applicability of statistical process control and related techniques to non-manufacturing or service activities. Charles D. Zimmerman III (1985), who was the vice chairman, service industries, of the Administrative Applications Division of the American Society for Quality Control in 1985, had the following to say on this subject: "We found that the concepts of quality control applied to the traditional manufacturing environment can be easily adapted to the service industry environment." William J. McCabe (1985), manager of quality planning at the IBM facility in Kingston, NY, agreed. "We confirmed that the control chart methodology is widely applicable to nonproduct efforts." Carol A. King (1985), president of The Quality-service Group in Princeton, New Jersey, disagrees. She says, "Quality control systems for service operations have special requirements that manufacturing systems do not fulfill." Lewis and Boom (1983) have similar thoughts: "Statistical controls do not have the same applica-

tion when 'mistakes' occur in human interpersonal interactions and intangible product attributes." Inspite of this disagreement several successful applications can be found in the literature and these will be presented throughout the remainder of this chapter.

<u>Nature of Variability in the Process</u>

One of the most important topics in statistical process control is the nature of variation in the process. Process variation can be manifest through variations in characteristics of the output or variations in characteristics of the process. Measurements of the characteristics of process output are process performance variables, and internal measurements of process characteristics are process state variables. Data can also be characterized as either variable or attribute in nature. Variable data is measured using a continuous scale such as length, weight, temperature, or viscosity. Attribute data is measured using a discrete scale as in counting the number of blemishes on a painted surface or simply judging a part good or bad. No matter what type of variable is used a target value is selected that represents the best value for that particular characteristic. Measurements are taken at different points in time and each measurement will differ from the next. The quality of a characteristic is judged in two basic ways. The first is average performance which is determined by how close the measurement comes to the target value. The second is dispersion performance which is determined by the variability of the measurements about the target value. Closely related to the target value are the specification limits which define how far a characteristic measurement can be from the target before it is considered unacceptable. It is worthwhile to repeat that, while the tar-

get value and variation are related to quality, the specification limits have nothing to do with quality. More will be said later about the nature of variability in the process.

Manufacturing Example

These concepts will first be illustrated using a part measurement since the application is the most direct in this case, then the concepts will be related to various non-manufacturing process and product characteristics.

Suppose the part under consideration is a crank shaft and the quality characteristic is the diameter of the bearing surface where the piston rod attaches to the crank shaft. This diameter is a process performance variable and is also a variable measurement as opposed to an attribute measurement. The bearing surface is turned on a special lathe and the diameter is measured continuously during the cut using a caliper that signals for the tool to withdraw when the target value is reached. The target value is the diameter that will provide the best fit when mated with the rod bearing. The specification limits are defined as a certain value above and below the target value, for example, 1.025 inches plus or minus .002 inches. The specification limits admit that the process is not capable of consistantly producing a diameter of exactly 1.025 inches and that no instrument is capable of measuring exactly 1.025 inches. Therefore, the diameters of these bearing surfaces will not be identical from one crank shaft to another for a number of reasons that will be discussed later. A crank shaft that measures close to the target value is of better quality than one that measures close to one of the specification limits. A crankshaft that measures beyond one of the specification

limits is not considered usable. If the diameter is too large it can be reworked, but if it is too small the part is scrapped.

In this example a product characteristic rather than a process characteristic is used to judge quality. This characteristic is also a process performance variable as opposed to a process state variable. It is measured using variable data. The average performance of the process is the average diameter and the dispersion performance is the variation in this average. The target value has bilateral specification limits.

A process characteristic in this example would be some measureable characteristic of the lathe such as turning RPM, feed rate, or depth of cut. Such a measurement is a process state measurement. A different product characteristic or process performance measurement that uses attribute data could be simply a count of the number of crank shafts that did not fall within the diameter specifications. The average performance of this characteristic would be the average percent defective and the dispersion performance would be the variation in this average over time. Of course, such a measurement contains very little useful data and contributes nothing to the pursuit of never-ending quality and productivity improvement. The target value may be as optimistic as zero percent defective with an upper specification limit equivalent to a lot tolerance percent defective or acceptable outgoing quality level. However, when considered using the correct definition of quality, an upper specification limit would not be explicitly defined under the assumption that the goal is to attain zero percent defective with no variance.

Non-Manufacturing Examples

Examples of non-manufacturing activities that can be measured using variable data are not very common. One such example is the SPEAK-UP! program mentioned earlier (McCabe 1985). The quality characteristic under consideration was the response time. McCabe measured this in units of days but this is still a continuous variable--he just chose to limit the accuracy of the measurements to unit values. It is a process state variable rather than a process performance variable, since it measures the time the product (the response letter) remains in the processing system. A process performance variable in this case might be the number of errors in each response letter or the number of times the letter had to be returned for rework. No target level was specified as is common in most non-manufacturing activities. A target level of zero, however, could be easily assumed based on their continuing improvement activities. No specification limits were given either, which is also typical of non-manufacturing activities, but this is of little importance since specification limits have nothing to do with quality anyway. The average performance is the average response time and the dispersion performance is the variation in this response time from one week to the next. We will return to this example to illustrate additional concepts and techniques of statistical process control.

The target in this case may seem unrealistic but it is no more unrealistic that striving for parts that measure exactly 1.025 inches in diameter. Reaching the target is not important in this case. What is important is having a goal that will motivate never-ending improvement activities. Therefore, the target value is not the goal and

neither is the span between the specification limits as in the crank shaft example; the goal is the reduction of variation in the process performance.

The next non-manufacturing example will illustrate the use of attribute data. This example is also taken from McCabe (1985). The IBM facility at Kingston, New York was growing rapidly and this required rearrangement of offices on a regular basis. Moving companies were hired to perform this task during non-office hours. The quality characteristic of concern to management was the number of problems encountered per move. This is an attribute measurement and is also a process performance variable. The average performance of the process is the average number of problems experienced in each move and the dispersion performance is the variation in this measurement from one move to the next. The target value was to have no problems on every move. McCabe used the upper control limit on his control chart as the upper specification limit. In other words, he decided that a mover's performance was unacceptable if they caused more problems than this limit on any move. It is important to emphasize at this point that a chart control limit and a specification limit are not the same thing. More will be said about control limits later but this is a common problem and must be avoided because it inhibits never ending improvement.

Notice in these two examples that specification limits do not have the same meaning when applied to non-manufacturing activities and [illegible] the analyst [illegible] this difference is of little [illegible] however, [illegible] limits have nothing to do [illegible]

tant in the past to implement statistical process control. Manufacturers place a great deal of importance on the product conforming to specification limits. In this respect the managers of non-manufacturing activities are in a better position to appreciate the concepts of statistical process control and the idea of never-ending improvement than were the managers of manufacturing activities. In fact, the evolution of quality control in the service industries would have been much faster if it had not been for the poor example of manufacturers. Quality control practitioners in service industries observed how quality control was being done in manufacturing industries and concluded that it could not be done in their operations since they were different. King (1985) noted that "a service quality assurance system must be designed to go beyond the product orientation of the manufacturing system." But this is the same direction in which manufacturing quality systems must move. Manufacturing is beginning to rely more and more on process control to assure quality, so the approaches of manufacturing and service industries will eventually converge (Thompson, DeSouza, and Gale 1985).

<u>The Significance of the Target Value</u>

The idea that a product performs best when all parameters of the product are at their ideal target values is something that must be understood in non-manufacturing terms. This idea is central to the Taguchi definition of quality and it serves as the motivation for never-ending quality improvement. Without a clear understanding of this idea a service manager will be content with good enough performance. This concept is easy to understand in the context of manufactured components that are part of a larger assembly due to the

problem of tolerance stack-up mentioned earlier. But what about non-manufacturing activities? How do their products fit together?

Consider the facility maintenance example again. The material control unit can operate efficiently only if it gets error-free purchase requests from planning. The product produced by planning (the purchase request) will perform best when it is at its target value of being error-free. The performance of the purchase request is to communicate to the material buyers exactly what material is required and how much of this material needs to be purchased. It will not perform this function well if it contains errors. A sequence of service activities can be thought of as producing a set of parts that must fit together properly in order for the system to operate efficiently.

What about service operations that stand alone? How is a target value selected and what does it mean for the product to work best when it is close to the target value? Consider the process of a lawyer providing advice to a client. This advice may be in the form of a legal document or in the form of verbal instructions. During a counseling session, the lawyer is producing a particular state of mind in his client. This is the product of his endeavors. The target value associated with this state of mind is the client's expectation. At the start of a counseling session, the lawyer will ask his client what he expects to receive from this particular legal action. The lawyer will assess this expectation in light of his knowledge of the law, and may find it necessary to adjust his client's expectation during the session. The client may expect more than is legally possible or he may not expect enough. In either case the client's expectation still remains the target value.

The lawyer's knowledge of the law and his skill at persuasion will determine how well he meets the target value. Excessive variation in his performance will mean that a large number of his clients leave his office without having their expectations realized. These clients will most likely not return and they will advise their friends likewise; and, as a result, the lawyer's clientele will dwindle. If the lawyer is successful in consistently meeting his clients' expectations, his clientele will grow. When it is put in these terms it is easy to understand that his product (the client's state of mind) will perform best when it is close to the target value (the client's expectation). This knowledge should cause the lawyer to continually seek for and remove causes of variation in his performance. Notice there is no room in this example for specification limits and that specification limits would do nothing to assist the lawyer in his quality control efforts.

Another way to look at this case is to consider the client's expectation to not only be the target value, but also the lower specification limit. As long as the lawyer is able to meet or exceed his client's expectation, he can consider his performance acceptable and the client will be satisfied with his state of mind at the end of the session. When he is unable to meet the client's expectation, his performance would be judged unacceptable. Since the lawyer is able to adjust the target value to some extent, it would be possible for him to persuade his client that his case is not as optimistic as it really is just to insure that the final outcome will exceed the client's expectation. This is not a good situation either since it would tend to undermine the client's confidence in the lawyer's ability to per-

rectly assess a legal situation. Even when looked at from this perspective, the lawyer's product works best when it is close to the target value.

Selection of Key Quality Characteristics

Another concept worthy of consideration is the selection and measurement of key quality characteristics. In the lawyer example, a key quality characteristic might be client satisfaction. The only way the lawyer could measure this characteristic is through some sort of feedback obtained from the clients. The lawyer could obtain this feedback in at least two ways. He could have each client fill out an anonymous survey after each counseling session. This type of feedback is often unreliable and incomplete. Many people would not bother to fill out the survey, and those who did may not be completely candid. The ones most likely to provide feedback are those who are extremely dissatisfied. Another way the lawyer can assess client satisfaction is through observation during the session. At the end of each session, he could rate his subjective assessment of the client's satisfaction on a three point scale: dissatisfied, satisfied, or very satisfied. This measurement could also be faulty because it would be natural for the lawyer is inject his personal bias.

Quality characteristics in the previous example are rather limited and difficult to define and measure objectively. It is more common for a service operation to have many measureable quality characteristics. The problem in such a case is selecting those characteristics that are the most important. Sometimes it is best to start with a quality characteristic that is already being measured or one that has readily available data. This is what was done in the case of Windsor

Export Supply (Baker and Artinian 1985) that was mentioned in an earlier chapter. They began their quality improvement activities using the duration from the time a bill was received until the time a check was issued for payment. This is a process state variable analogous to the flow rate in a fluid processing system. Within the entire system several process performance variables were selected for further analysis if required. A preliminary statistical study of one of these indicated that billing error rates may be low enough to reduce the 100% audit of the bills to an audit of a sample at periodic intervals.

Special and Common Causes of Variation

The use of control charts is the technique employed by statistical process control to control the variation in a process. To understand how they work it is necessary to understand some more about the nature of variation in the process. As mentioned earlier, the operation of a mechanical process is subject to forces that cause variation in the quality characteristics of the output and the same is true of all non-manufacturing processes. These forces can be placed into two different categories: special causes of variation and common causes of variation.

These causes of variation will be illustrated using the process of rolling a pair of dice. On a single die each number from one to six has an equal probability of occurring. When two dice are thrown and the sum taken, the possible numbers from two to twelve have unequal probabilities of occurring. Two and twelve can only occur due to one combination, but there are three ways the sums of six, seven, and eight can occur.

Let the production system be the pair of dice and the operating procedure be to shake the dice in a container so they tumble uncontrollably, then release them onto a smooth table top. If this process was performed on a continuing basis and the results inspected each time, the inspector would have enough evidence to conclude that a fair pair of dice were being used and that they were being thrown in such a way as to prevent the operator from having any control over the outcome. This system would be operating under a constant system of common causes. The variation in the output from one throw to another would be explained as resulting from the structure of the system and nothing else. A list of the common causes of variation in this system would include the pair of cubic dice with its six faces marked from one to six, respectively; each cube balanced so that one face is not heavier than another; and random, uncontrollable motion of the dice while they are thrown.

Now suppose the inspector observes a suspiciously high number of twelves occurring. He may suspect that something has changed in the system so that another force besides the set of common causes is effecting the outcome. It may be that the system has been altered. For example, two faces on each die may be marked with a six or each die may not be properly balanced. Another cause may be that the operator is using a container to shake the dice in that prevents them from tumbling so the operator can control which numbers occur. It may be that the operator feels that higher numbers are more desirable, so he has learned how to shake the dice in the container and release them onto the table without changing which faces are up. The first two causes of variation are due to changes in the production system

itself, and the last two causes of variation are due to changes in the operating procedures. These causes of variation would be classified as special causes since they are not part of the expected natural process variation.

Over-Control and Under-Control

If such a change were to occur in the operating system, an unsuspicious inspector may require a great deal of evidence before he would conclude that something had changed. A suspicious inspector, on the other hand, would require very little evidence and in some cases may suspect that something is wrong even without sufficient evidence. The unsuspicious inspector would wait too long before identifying and removing the special cause of variation. This is under-control. The suspicious inspector, however, would stop the process too frequently looking for special causes and may implement unnecessary changes in operating procedure. This is over-control.

The use of the concepts of statistical process control and the control chart technique gives the objective inspector the right kind of statistical information to judge confidently when a special cause of variation is present in the process. This avoids the dual problems of over-control and under-control. The interpretation of the control charts can be modified to reflect the level of confidence an inspector wishes to have in detecting a special cause before taking corrective action. If the inspector wants to be 95% confident, it is likely that he will miss some special causes of variation. He would be considered an unsuspicious inspector and this may result in under-control. If the inspector wishes to increase his chances of detecting a special cause of variation, he may specify a confidence level of 90% or even

85%. This, however, will increase his chance of reacting to output variation that is due merely to common causes. He would be considered a suspicious inspector and this may result in over-control of the process.

This example is directly analogous to any manufacturing or non-manufacturing operation and illustrates the difference between special and common causes of process variation. The illustration, however, has one shortcoming. It does not contain a definition of a desired quality characteristic. Suppose the desired outcome is seven. If the system is operating as designed, the outcome of seven is likely to occur three out of every twenty-one tries. The chance of being close to seven (six, seven, or eight) is likely three tries in every seven. This is all that can be expected from the current system and the first duty of the operator is to insure that it remains consistent. In order to improve the outcome of the process (get more numbers near seven), something would have to be done to change the system itself--something that would alter the constant system of common causes. This illustrates the idea that the operator of a process is in a position to identify and remove special causes of variation, but it takes a radical change in the system to effect removal of common causes of varition. This action can only be done by management.

Control Charts

Statistical process control offers several control chart techniques that may be used to identify special causes of process variation and maintain statistical control of the process. Examples of the use of these charts are common for manufacturing activities, so the remainder of this chapter will use only non-manufacturing examples to

illustrate their use. Adequate instruction on the construction of these charts is also available in other references so will not be covered here. (See, for example, Grant and Leavenworth 1980 or Oakland 1986.)

The type of control chart used depends on the kind of data that is available for analysis. Variable data is analyzed using the X-bar and R control charts which are employed as a pair. These charts provide the most diagnostic information about the process and are the best ones to use. Several charts are available for analyzing attribute data. These are the c-chart, p-chart, u-chart, and d-chart.

First it will be necessary to introduce two additional terms: defect or nonconformity, and defective. A defect or nonconformity is a fault with the product or service that may or may not make it unfit for use. Every problem caused in a rearrangement move is considered a defect in that move. A product or service is considered defective if it has one or more defects. When a purchase request has an inadequate part description, it contains a defect and is considered defective until the defect is corrected. In this case the single defect causes the purchase request to be unfit for use. In the case of office rearrangement moves (McCabe 1985), each problem encountered is a defect, and each move that contains problems is considered a defective move. However, in that example it took a specified number of problems in one move for that move to be considered unacceptable. Each move may also contain a number of different problems or defects.

The p-chart is used to control the fraction defective in a sample. The defective items in the sample may each contain one or more defects but this information is not taken into account, so the

p-chart loses some of its diagnostic ability. The d-chart is a simplification of the p-chart. It is a control chart for the number of defectives in a sample rather than the fraction defective. The c-chart, on the other hand, considers the frequency of occurrence of each type of defect. It is a control chart for the number of defects. Not only are the defective items removed from the sample, but each occurrence of a defect is counted and analyzed. It is common for the sample size to consist of one item. The u-chart is a variation of the c-chart and is necessary if the opportunity space for the occurrence of defects varies from one sample to the next. It is a control chart for the number of defects per unit.

Each of these charts has associated with it an average performance level and upper and lower control limits. Table 1 lists the formulas associated with each control chart, and Table 2 gives some of the control limit factors for the X-bar and R control charts. These limits serve as a statistical confidence interval around the average performance and statistically significant conclusions can be made about each data point on the chart. A concise set of rules for interpreting these data points are given in Figure 4 (Nelson 1984). If any of these rules are violated, it can be concluded that a special cause of variation is present. If this cause of variation indicates an increase in variation, it must be identified and removed. If it indicates a decrease in variation or an improvement in performance, it must be identified and continued.

The control charts are used to show that the process is either in statistical control or out of statistical control. A process that is in statistical control is under a constant system of common causes. A

Table 1
Basic Control Chart Calculations

$\bar{X}$-Chart

Statistic = $\bar{X}$ = sample average

Center Line = $\bar{\bar{X}}$ = average of sample averages

Upper Control Limit = $\bar{\bar{X}} + A_2\bar{R}$

Lower Control Limit = $\bar{\bar{X}} - A_2\bar{R}$

Sample Size = $n \leq 10$

R-Chart

Statistic = R = Range

Center Line = $\bar{R}$

Upper Control Limit = $D_4\bar{R}$

Lower Control Limit = $D_3\bar{R}$

(Typical values for A_2, D_3, and D_4 given in Table 2.)

p-Chart

Statistic = p = proportion defective

Center Line = $\bar{p}$

Upper Control Limit = $\bar{p} + 3\sqrt{\dfrac{\bar{p}(1-\bar{p})}{n}}$

Lower Control Limit = $\bar{p} - 3\sqrt{\dfrac{\bar{p}(1-\bar{p})}{n}}$

d-Chart

Statistic = np = number of defectives

Center Line = $n\bar{p}$

Upper Control Limit = $n\bar{p} + 3\sqrt{n\bar{p}(1-\bar{p})}$

Lower Control Limit = $n\bar{p} - 3\sqrt{n\bar{p}(1-\bar{p})}$

c-Chart

Statistic = c = number of defects per inspection unit

Center Line = $\bar{c}$

Upper Control Limit = $\bar{c} + 3\sqrt{\bar{c}}$

Lower Control Limit = $\bar{c} - 3\sqrt{\bar{c}}$

u-Chart

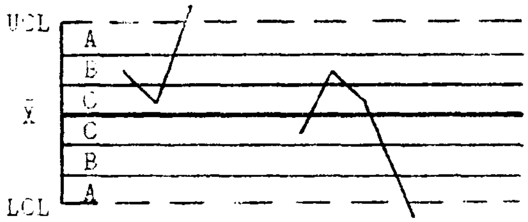
Same as c-chart only c needs to be divided by the opportunity space for each inspection unit to yield defects per unit.

Table 2

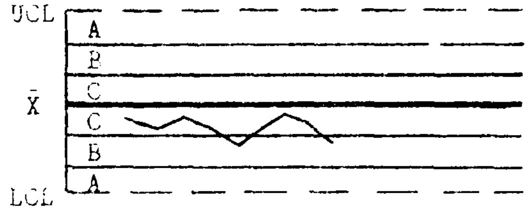
Control Limit Factors for $\bar{X}$ Chart
(Grant and Leavenworth 1980)

Sample Size n	$\bar{X}$ Control Limits A_2	Range LCL D_3	Range UCL D_4
2	1.88	0	3.27
3	1.02	0	2.57
4	0.73	0	2.28
5	0.58	0	2.11
6	0.48	0	2.00
7	0.42	0.08	1.92
8	0.37	0.14	1.86
9	0.34	0.18	1.82
10	0.31	0.22	1.78

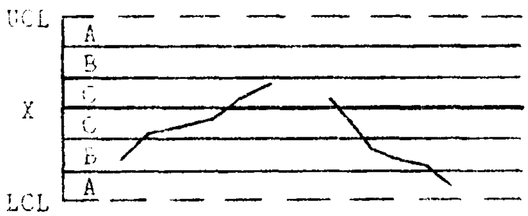
Test 1. One point beyond Zone A



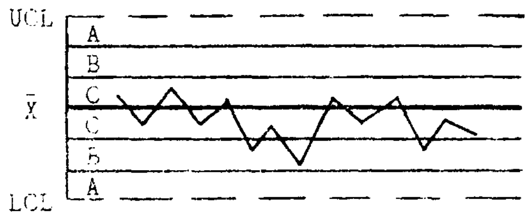
Test 2. Nine points in a row in Zone C or beyond



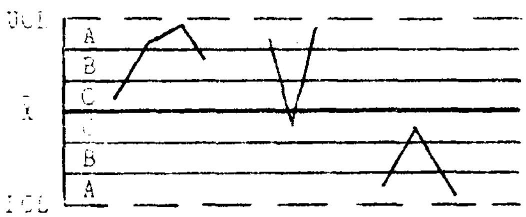
Test 3. Six points in a row steadily increasing or decreasing



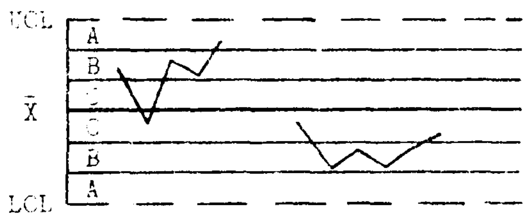
Test 4. Fourteen points in a row alternating up and down



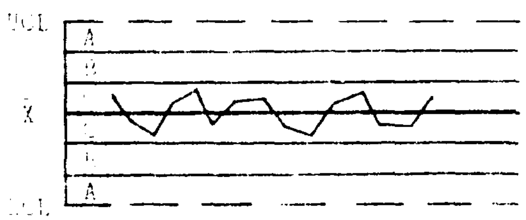
Test 5. Two out of three points in a row in Zone A or beyond



Test 6. Four out of five points in a row in Zone B or beyond



Test 7. Fifteen points in a row in Zone C (above and below center line)



Test 8. Eight points in a row on both sides of center line with none in Zones C

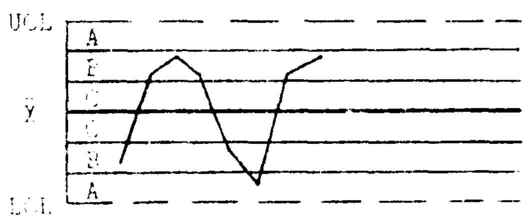


Figure 4
Illustrations of Tests for Special Causes
Applied to Shewhart Control Charts
(Nelson 1984)

process that is not in statistical control has one or more special causes of variation present.

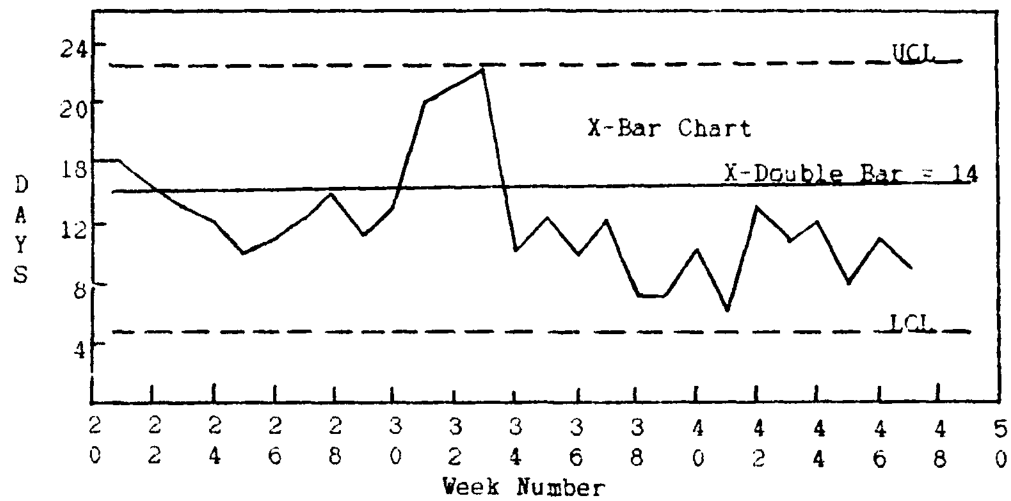
Following are several examples of the applications of these charts to non-manufacturing activities. In these examples significant concepts of statistical process control will be highlighted.

X-Bar and R-Chart Example

The first example will be a return to the SPEAK-UP! program (McCabe 1985) used earlier. Here is a quick summary of how the progam works. An employee sends an informal letter to the program administrator who types the letter and insures anonymity. This letter is then sent to the appropriate functional manager who writes a reply for the signature of a senior manager. Once the reply is signed it is returned to the program administrator who sends it to the employee. The critical quality characteristic for this process is the response time. If the response is not timely the employees will lose confidence in the system and in management.

Each reply letter had to meet the following criteria: admit mistakes, describe changes, answer all questions, not be defensive, be short, be written in the style used by the senior manager.

Management began its study by examining the historical data and noticed that some functional areas took longer to reply than others. They took a sample of five response letters each week from their files for twenty weeks to set up the control chart shown in Figure 5. The control chart for the first twenty weeks showed statistical control meaning that no special causes of variation were operating on the system. This indicated that management action would be necessary if improvement was desired. The average response time of fourteen days



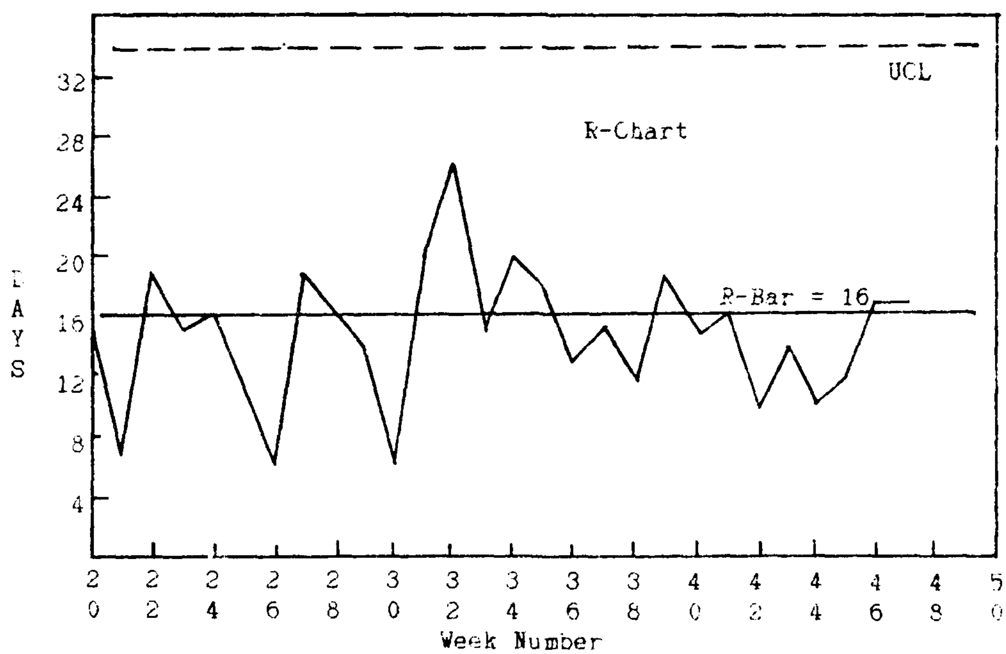


Figure 5
Speak-Up! Response Times
(McCabe 1985)

was too long, so management did two things. They began tracking and publishing the average response time for each functional area to promote some healthy inter-area competition. The second thing they did was to set up a workshop for those responsible for writing the replies so they would know exactly what was required. The run below the average between weeks 20 and 30 reflects a significant decrease in the average response time during that time period. The same is true from week 34 and on. Weeks 32 and 33 indicate another out-of-control condition (two out of three points beyond two standard deviations from the mean) meaning a statistically significant difference in the average response time had occurred. The cause of this variation was that the trained managers were on vacation and their assistants, who had not been to the workshop, were writing the replies.

The charts as initially set up showed statistical control for the first 20 weeks. The response rate tracking and workshops were special causes of variation in this process which caused the X-bar chart to go out of control below the average. (A run of eight or more points either side of the mean is an out-of-control signal.) In this case the change was desirable and maintained. The change in the control chart verified that the corrective actions were effective and the process was operating at a lower average response time. Since this was true, the mean and control limits should have been recalculated. This would have made the out-of-control conditions at weeks 32 and 33 even stronger.

Results of Improvement Efforts

Now a few comments about the way they collected and analyzed the data. A sample of five response letters was taken each week. When

taking a sample it is important that all items in the sample come from the same process; meaning that the same system of causes of variation was in effect for each item in the sample. This system of causes may comprise both special and common causes. To accomplish this it is important to take all elements of a sample close together in time--preferably consecutively. (This is effective at detecting abrupt, sustained shifts in the mean. A more distributed sample may be required if gradual shifts, or sporadic and short-lived shifts in the mean are suspected.) It is also important that the samples do not represent a mixture of different processes. In this case each functional area manager was a separate process so the data was a mixture. This would explain the high mean on the R-chart which indicates a great deal of variability in the process--each separate process adds to the system of common causes of variation. Although McCabe achieved significant results it would have been desirable to separate the streams of data--one stream for each functional unit. Of course this requires more work but may be necessary to achieve further improvement.

Another item to be considered in this example is the matter of productivity. This is not mentioned by McCabe but the response time improvement was due to a reduction in the number of letter revisions required. Of course this will give the functional area managers more time to do other things so their productivity will improve if they use this new-found time wisely. The senior managers should also experience an increase in available time since they would not have to review the reply letters as carefully to insure acceptability.

This example was used earlier to illustrate the "make-inspect-sort-rework-scrap" cycle. Let's see how the use of statistical process control changed this counter-productive cycle into the "data collection-analysis-feedback-corrective action" cycle. Data collection and analysis were being performed at the time weeks 32 and 33 arrived and some functional area managers went on vacation. The analysis showed the out-of-control condition and revealed the reason. Corrective action insured that assistant managers were also trained. During this process, however, it was necessary to do some inspection and rework on the unacceptable letters, so the old cycle was not completely abandoned. As additional causes of variation are identified and removed, it may be possible to discard the counter-productive behavior altogether.

Earlier in the chapter it was said that the target value for this process was immediate response. No upper specification limit was mentioned, but in most similar cases where response time is important, an upper limit is either set by company policy or law, so it most likely existed in this case as well. The closer the response time is to the target value, the better it will be at performing its primary function--facilitating communication up and down the levels of management. Communication is most effective when feedback is immediate--as in a good face-to-face discussion. The specification limit enters the picture only to assess the capability of the system. More will be said about process capability later.

c-Chart Example

The case of office rearrangement moves (McCabe 1985) is an example of the use of c charts. The number of problems encountered on

each move were plotted on the chart. This is analagous to plotting the number of defects found on a printed circuit board. This chart is shown in Figure 6. They used the first twenty moves to establish the chart control limits. The average number of problems per move was 4.3, and the upper control limit was calculated to be eleven problems per move. A number of contractors were involved in performing this service, so the improvement strategy was to motivate the contractors to improve their own performance. If a contractor caused more than eleven problems in one move he was put on notice, and if this happened a second time he was removed from the list of contractors to be called. This new system was phased-in during the period indicated on the chart between weeks 20 and 36. One contractor (move 45) was put on notice after the phase-in period, and after that virtually all problems disappeared. New control limits were calculated once the system showed significant improvement. This new limit was used to maintain process performance.

A contractor who caused more problems than the upper control limit on the chart was considered to be a special cause of variation. There was something about that contractor's performance that was different from the others. The company did not try to determine the cause of this problem--they left that up to the individual contractors who did a very good job of eliminating problems once they knew it meant retaining their job.

In this case all problems were lumped together. One useful feature of the c-chart is that various types of problems or defects can be charted individually or in smallar groups. This gives the chart more diagnostic ability. The solution action (putting a contractor on

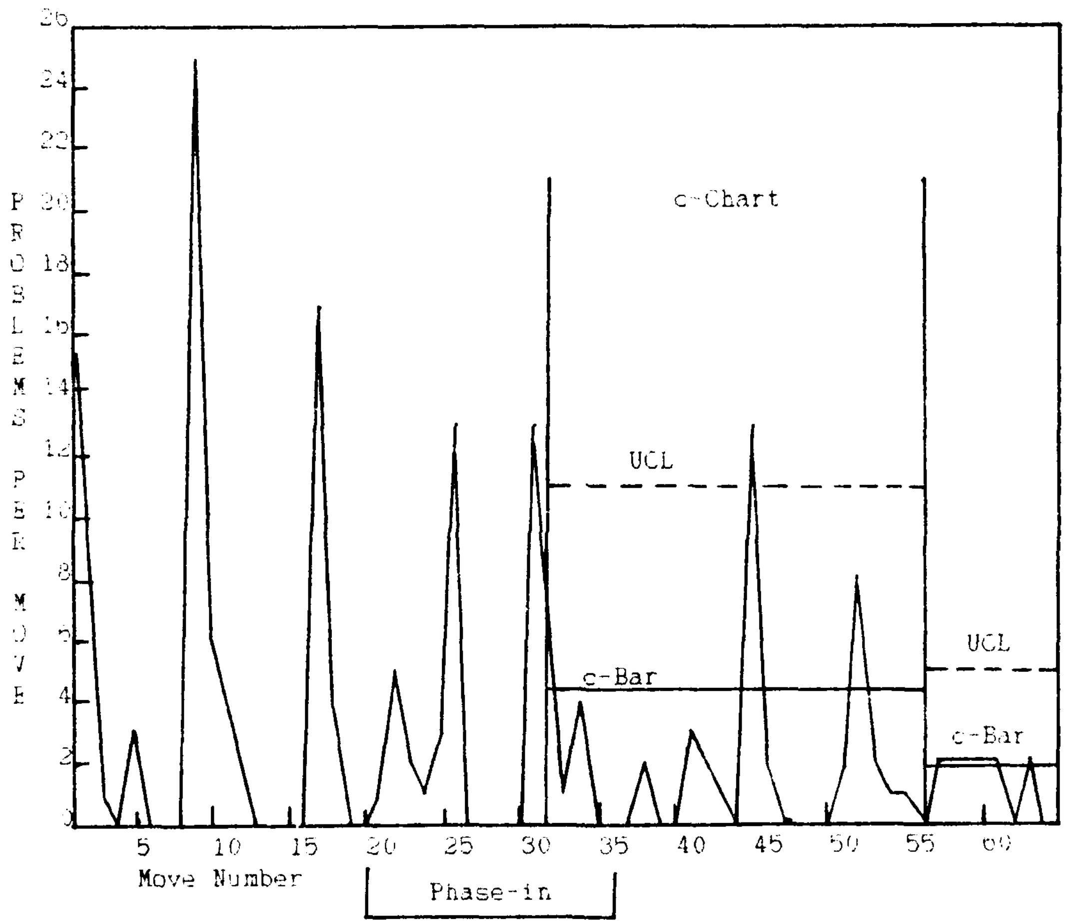


Figure 6
Rearrangement Moves
(McCabe 1985)

notice) was simple in this case and it worked. It did not require any problem solving effort. Some problems are more difficult to solve, and the increased diagnostic capability of the c-chart if individual problems are kept track of is valuable.

p-Chart Example

McCabe (1985) also gives an example of the use of a p-chart. The problem in this case was the number of purchase order documents that contained errors. This information was collected for a twenty-week period and used to construct the chart shown in Figure 7. The average error rate for the first twenty weeks was 5.9%, but the process in force between weeks 23 and 29 was clearly not the same process that was used to calculate the chart parameters. Although a special cause for this improvement was not identified, the average and control limits were recalculated to reflect the performance of the new process. After that was done one out-of-control condition appeared which revealed that vacations again were the cause.

These examples demonstrate a very important point. In each case management knew something was wrong and needed improvement. The typical response to this knowledge might be to admonish the buyers in the purchasing department to be more careful when making out the purchase orders, for example. Marcum (1985) provides the following insight: "In times past, the quality practitioner was sometimes somewhat limited in his understanding of how to analyze the problems that were being brought to light by the statistical data system. He might not have understood the meaning of the 'root cause' of a problem. And even if he did, he probably lacked the time and training to track the problem back to its root cause. However, without this type of analysis, the

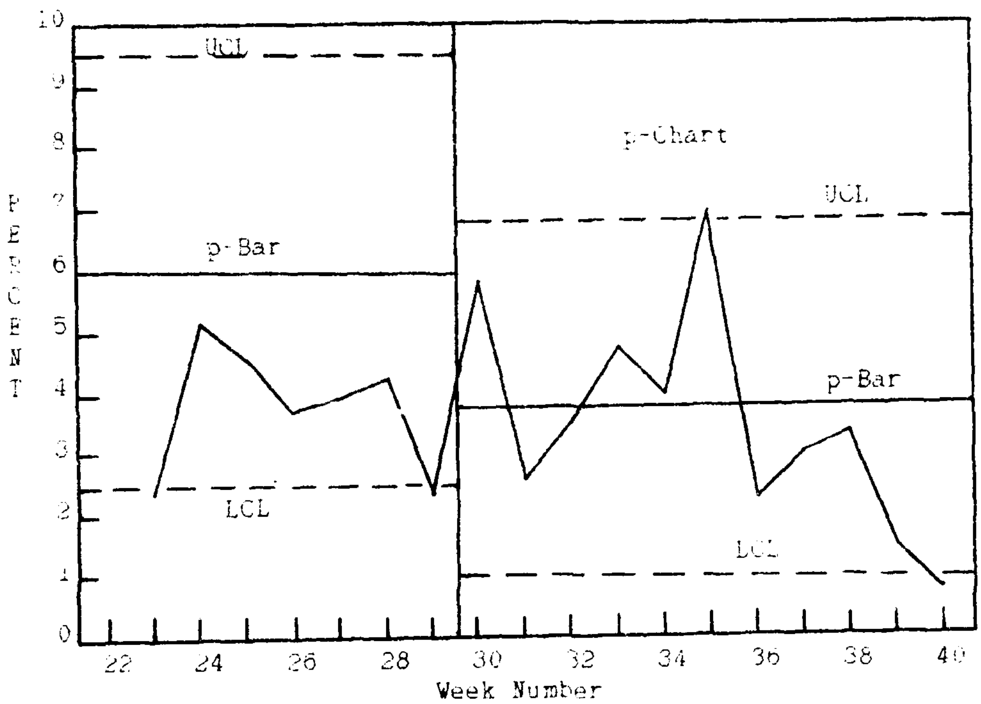


Figure 7
Purchase Order Documents Containing Errors
(McCabe 1985)

chances of resolving real problems were very slim: the end result of corrective action investigations was frequently, 'operator responsible--operator reprimanded.'"

The control charts provide a means to focus corrective action on the root cause of a problem. Buyers who are filling in for someone else who is on vacation should not be reprimanded for an error rate that is too high because they have assumed an extra workload and are doing some work with which they are not familiar. The focus of corrective action should be on preparation for vacation periods so the workload will not be too high and the replacement buyers more prepared to assume the unfamiliar tasks.

Fault Diagnosis

The service manager does not have the same means available to correct his process as does a manager of a manufacturing activity. Often times it requires more imagination on the part of the service manager to effect meaningful changes in his processes. Too often they rely on improving the attitude and ability of the performer and ignore the possibilities available through improvements on the system as a whole. This is analogous to what many manufacturers have also done. When faced with a machine that is not meeting their requirements, they are inclined to replace it if they cannot improve its performance.

Manufacturing and non-manufacturing managers each have available the same set of tools with which to analyze their problems. Among these tools are the Ishikawa cause-and-effect diagram, Pareto analysis, simulation, and design of experiments.

The Ishikawa cause-and-effect diagram (Kindlarski 1984) and Pareto analysis are both useful in locating the most effective area at

which they should focus their analysis efforts. The Ishikawa diagram is also very useful in solving problems revealed by other methods such as statistical process control. Examples of the use of these two methods are in Chapter 6.

Design of experiments is valuable when analyzing a system that is affected by a number of variables, and the individual effects of these factors and how they interact with each other are not known. The application is direct in most manufacturing cases, but it is much more difficult to experiment with service operations in which the performance of people takes the place of the performance of machines. Human performance is usually affected by a complex set of intangible variables that cannot be adjusted at will. It is possible to adjust the operating characteristics of the system as a whole, however. This would involve actions such as a change in operating procedure, change in a form, or a change in office layout or equipment. These changes are more extensive and require more effort than simply changing the operating parameters of a machine and measuring the effect. Changes in procedure require a period of training before the true effects of the changes can be measured. And once a change is made it is nearly impossible to reverse it to what it was before in order to try a different experimental combination.

To alleviate some of the difficulties in applying design of experiments to service operations, computer simulations of the operations can be used. These models can then be used as the subjects of experiments to determine the most likely area to change. As shown in Chapter 6, if the variation in the service time is reduced, so is the average time a customer expects to remain in the system.

In these examples, little was said about common causes of variation. In making physical measurements, as in the crank shaft example, the accuracy of the measuring instrument is one significant cause of variation. This cause of variation may not be as apparent in non-manufacturing activities. Take, for example, the measurement of a period of time as in the SPEAK-UP! response time case. The measurement instrument in this case was the date on the employee's informal letter and the date recorded by the program administrator that the reply was returned to the employee. It is easy to imagine various sources of inaccuracy in this measurement process.

Process Capability

In manufacturing, process capability is a measure of how consistent the process is at making product that falls within the specification limits. Put another way, it is a measure of the confidence one can have that the process will manufacture parts that conform to the specifications. This measurement is calculated using the standard deviation of the quality characteristic measurement. A process that is capable to six standard deviations (a capability of six sigma) is likely to produce product within specifications 99.7% of the time if the process average is centered on the target value and the specifications are bilateral and symmetrical. Another assumption associated with this figure is that the quality measurements come from a normal distribution. This is not always true. The measurements could come from any distribution. The process must also be in statistical control. This capability may sound good, but it means that three parts out of every thousand are likely to be unacceptable and considerable care will be required to insure the process remains centered and free

of special causes of variation. Many manufacturers are now striving for a defect rate that is measured in parts per million, and a process that is much more capable than six standard deviations is required.

The concept of process capability takes on a somewhat different meaning when applied to service operations. Most of the time the target values in a service operation can be expressed by the two phrases "the more the better," or "the less the better." If one is considering errors in a document, the phrase "the less the better" is appropriate. If one is considering the amount of service provided for a set fee, the phrase "the more the better" is most appropriate. Similar situations exist in manufacturing as well. For example, if the characteristic is strength or durability the more of this there is the better. If the characteristic is blemishes on a painted surface the less there are the better. Rarely does a non-manufacturing activity have a quality characteristic that has bilateral, symmetrical specification limits. In contrast, this is common in manufacturing.

One example of the capability of a non-manufacturing process is given in Chapter 6. The quality characteristic is response time and the upper limit on this response is five days. The target value is zero so the shorter the response time is the better. The process capability in this case is a measure of how likely the process is to respond before that five day deadline expires. If the process capability is high this means that management can be very confident in promising a response before five days have passed. If the process capability is low, management would be very hesitant to make any promises.

In the previous example the process capability was easy to measure. But what does it mean to measure the capability of a process that consists of human performance? Take the process of typing, for example. There are two important quality characteristics: speed and accuracy. Speed is measured in words per minute and the faster it is the better. Accuracy is measured in errors committed and the fewer there are the better. The process consists of a human operator and a keyboard. There may be a lower specification limit on the speed, say 50 words per minute; and associated with this speed would be an accuracy level, say in this case zero errors. The statistical analysis typical of manufacturing process capability studies does not apply. It is possible to make some predictions about the typist's capability by measuring his average performance and the variation about that average; and estimating how likely it is for the typist's speed and accompanying accuracy to fall below the lower specificaiton limit. There is something more personal about the idea of having confidence in a process like this. This kind of confidence goes beyond the sterile statistical analysis. A manager may be confident in a typist's ability even is his typing ability is currently below the lower specification limit. This confidence has to do with the manager's subjective assessment of the typist's ability and motivation to improve. These elements cannot enter into the capability assessment of a mechanical process.

In any type of human performance, the act of measuring that performance will have an effect on how well it is done. Consider the typist again. He may perform better when his typing speed and accuracy is being tested than he does while doing his routine typing. A

manager may see a discrepancy between the typist's measured capability and his apparent capability. The manager would subjectively assess his apparent capability by observing how many typed documents are produced and how accurate they are. He may also observe the size of the typing backlog on his typist's desk. In this situation the apparent capability carries more weight than the measured capability because the manager's confidence is built on his subjective assessment, not on the objective outcome of a typing test. He may compensate by getting documents and letters to his typist as early as possible; or, if the situation is severe enough, the typist may be fired or reassigned.

CHAPTER 5
Implementation of Statistical Process Control

Although Shewhart control charts are simply techniques to be applied in a quality/productivity improvement program, the whole philosophy of statistical process control affects all the surrounding quality/productivity related activities. Therefore, there are a number of activities that must occur before statistical control charts are employed, and there are also a number of activities that should occur as a result of the proper use of these charts. The entire implementation process can then be divided into three distinct stages: Stage 1, define the system; Stage 2, apply the techniques of statistical process control; and Stage 3, cause the quality/productivity improvements to propagate to surrounding activities.

Stage 1

Stage 1 takes care of the preliminary work required before the techniques of statistical process control can be employed. This stage consists of seven tasks or steps:

1. Select the processing system to analyze.
2. Define the system boundaries.
3. Define the flow across the system boundaries.
4. Define the suppliers and customers of the system.
5. Operationally define quality requirements for resources coming into the system.
6. Define or obtain customers' quality requirements for resources leaving the system.
7. Diagram the internal sequence of operations.

The first task (selecting the processing system) may seem trivial. It is often difficult, however, to limit the scope of analysis to something that is easily managed yet substantial enough to offer significant results. This is the purpose of the first step. It is also important for another reason. The system selected for analysis should be owned by the manager who will be using the quality control system. The concept of ownership is crucial to process management because the basic criteria of ownership is having the authority to make changes in the system (Melan 1987). This authority may be as restricted as simply following procedures and executing tasks, or may be expanded to include greater levels of autonomy. Even under the most restricted sense of the term an operator still retains ownership over the manner in which he follows procedure and executes tasks.

It may be necessary to make a tentative decision on the system to analyze, then go on to the remaining tasks in Stage 1. The definition of the system will be refined as the analysis progresses through the subsequent steps. Consequently, the work done at each step is always subject to change.

Defining the boundaries of the system (Step 2) will determine what the flow is across these boundaries (Step 3) and who the external suppliers and customers are (Step 4). These boundaries will also add further definition to the system selected in Step 1. A good place to start is with the complete unit that is owned by the manager doing the analysis. Many separate processes may be included if the unit is large or complicated, so it may be necessary to focus attention on one process at a time. In this case the boundaries would be drawn around the work units or tasks that form one process only. An analysis may

begin with the entire functional unit, then confine itself only to those processes revealed by the initial analysis that require the most improvement.

The boundaries of the system also define the producer-user interfaces that will be the subjects of analysis further on in the implementation process. Baker and Artinian (1985) list the following as elements of the producer-user interface: producer processing system, producer inputs, producer outputs, producer output requirements, user processing (receiving) system, user input requirements, producer's feedback loop (customer satisfaction), producer's feedback loop (process control). Each of these elements are incorporated in this implementation process.

The flow across the system boundaries (Step 3) refers to the flow of resources. This is analogous to the flow of materials supplying an assembly line or the flow of fluid in a chemical refinery as it passes from one process to the next. The term "resources" is used because of its generality. The resources used and produced by non-manufacturing operations are much more varied than those of manufacturing. The flow of resources in non-manufacturing may indeed consist of materials such as finished documents and forms, but it may also consist of verbal exchanges of information.

The flow of resources into the system are of two basic types. One type consists of those resources that the system adds value to by performing its assigned tasks. An example of this may be a building design that a contractor translates into a construction cost estimate. The second type of system input are those resources that the system requires in order to transform the first type of input. In the con-

tractor example these inputs would consist of such things as the information contained in Means Construction Cost Estimation Guide and the personal experience of the contractor.

The flow of resources out of the system are simply the products of the system.

Step 4, define the customers and suppliers, follows directly from the results of Step 3. It is very likely for an operation that is internal to an organization to receive inputs and produce outputs without ever having an idea who their suppliers are or who their customers are. This is an unfortunate situation which increases the importance of this step. Deming (1982) has observed that simply knowing who the customers are and understanding their needs and expectations can lead to quality improvement.

The operational definition of incoming resources (Step 5) adds objectivity to the measurements that are required for statistical process control. An example of a definition of quality that is not operational would go something like this: verbal work requests received from customers will contain a complete description of the work required. An operational definition would go like this: the work description on a verbal work request will contain answers to all the questions on the supplied checklist. An operational definition defines how a particular quality characteristic will be measured. This definition will be used to inform suppliers of the system's quality requirements and also to assess the performance of each of the system suppliers.

Step 6 also requires operational definitions of quality. In this case, however, the quality requirements of the customer need to be

defined. Sometimes it may be possible to simply ask the customer what his quality requirements are. If the customer is also using statistical process control this information should be easily obtainable. If he is not, his reply may not be in operational terms so it will be up to the manager of the system to translate these customer requirements into operational quality definitions. In some instances it may not be possible to communicate directly with the customer, or the customer himself may not have a clear notion of what his quality requirements are. If this is the case the system manager will have to define the customer requirements on his own. This is a crucial step, because without these definitions the manager will not be able to assess whether or not his system is meeting his customers' requirements.

A diagram of the internal sequence of operations (Step 7) serves as an analysis aid. This diagram will show all the processing steps and the system boundaries. All external elements to the system required to identify producer-user interfaces will also be shown. When this step is complete it may be apparent that the system should be redefined and the boundaries redrawn. As further analysis is conducted on the system, this diagram will assist in locating specific problem areas that may require individual attention. If such an area is identified it would become the system to be analyzed and the process would start all over again.

Scanlon and Hagan (1983b) provide the following insight that summarizes the steps of Stage 1: "Basically speaking, instant quality and productivity improvement could be achieved if each employee of the company knew the answers to the following questions: What is my job? Where do I fit in general terms in the organizational structure? Who

do I receive my work from? What do they do? Why do they do it? How do their errors affect me? After I finish my work task, who receives the work? What do they do? Why do they do it? How do my errors affect them?"

Stage 2

Stage 2 covers the actual use of statistical process control on the system that was defined in Stage 1. It consists of five steps:

1. Collect data.
2. Analyze the data.
3. Bring the process into statistical control by removing special causes of variation.
4. Maintain statistical control using the control charts.
5. Improve the process by identifying and removing common causes of variation.

When collecting data on the system (Step 1) it is important to give careful consideration to the quality characteristic that will be measured. To begin with it may be best to use data that is already being collected so the implemention of statistical process control is less tramatic to the established system. Usually there is a lot of room for improvement in a process that has never been under statistical control; and even if the quality characteristic being measured at the beginning is not the best, improvement can still be realized. The quality characteristic should be one that has a direct relationship to the needs of the customer.

Aubrey and Eldridge (1981), executives of Continental Illinois National Bank and Trust Company of Chicago, describe the selection of quality characteristics in terms of quality deviations. Quality devi-

ations are specific problems encountered in the work process. They collect all the possible quality deviations for the system that is being analyzed. From this list they select key quality deviations that significantly affect the customer or that are costly to correct. Measurements of these quality deviations are then developed and they begin to collect data. The following question should be answered when selecting these key quality characteristics: What is it about this process that is critical to its success?

People in general do not like to have their performance measured and this characteristic is even more prevalent in service industries where performance measurement is more personal. Scanlon and Hagan (1983a) list three important reasons why measurements are necessary and then offer an admonition. The first reason for measurement is to establish where an organization stands in relation to its standards in order to identify and justify improvement actions. The second reason for measurement is to establish a base-line against which the results of any improvement actions can be compared. And the third reason is just the opposite of the second--to identify when specific problem areas arise in the system. Now the admonition--they warn that the "lack of measurement always penalizes the good performer and rewards the bad." In addition, measurement is necessary if all the advantages of statistical process control are to be realized.

The data collected may be either variable or attribute. It is better to use variable data whenever possible since the X-bar and R-charts are more diagnostic than the attribute charts. It may be possible to collect data that directly represents a quality characteristic of importance to the customer. This type of measurement is

called a process performance measurement. [illegible] it is not possible to measure any quality characteristic [illegible] final product of a service transaction since the product is [illegible] as it is produced. In cases like this it is necessary to [illegible] some key characteristic of the process and use this as a surrogate measure for the product quality. This type of measurement is called a process state measurement.

The data samples must be collected in a rational manner. Samples of variable data should be taken from consecutive units of output except when abrupt, but short-lived shifts in the mean are suspected. Samples of attribute data should be taken from the same size opportunity space. Data from two or more different process streams should not be mixed. Each separate process should be analyzed individually. The controlling criteria in determining the rationality of a sampling method is that the opportunity for a special cause of variation should be minimized within a sample and maximized between samples.

There are two dangers if rational sampling is not assured. The first is that the control charts may show false statistical control. This is particularly true on the X-bar and R-chart. The introduction of additional variation into the system may cause the average variation on the R-chart to be higher than it should be and this will cause the control limits on the X-bar chart to be too wide. The second danger is that the control chart may signal a special cause of variation when none exists. Effort could be wasted searching for a special cause of variation in the process when a simple change in the sampling method is all that is required.

The data is recorded and analysed using appropriate Shewhart control charts (Step 2). Five of these charts were presented in Chapter 4 (X-bar and R-chart, c-chart, p-chart, u-chart, and d-chart) and their use will not be repeated here.

The first task in analyzing data with control charts is to bring the system into statistical control by removing special causes of variation (Step 3). This may be a long process or the charts may show statistical control right from the beginning. Special causes of variation may be due to forces acting on the process or may be due to some irrationality in the sampling method as mentioned earlier.

The control chart does not solve process problems; it merely signals when one occurs. This in itself is a valuable piece of information because it eliminates the tendency of a zealous manager to over-control the process and it prompts a complacent manager into action when it is needed. An intimate understanding of the operating procedures of the process are required to solve many of the problems revealed through the control charts. The operator of the process is the one who knows the process best and can probably identify a process change that occurred at the same time the control chart showed an out-of-control condition. This source of information needs to be exploited and the best way to do this is to train the operator in the use of statistical process control and place the control chart in his hands.

Maintaining statistical control through the use of control charts (Step 4) suggests that this is something that does not end once all the desired improvements have been made. The frequency of sampling may be reduced but the process performance must be monitored continually to insure that no improvement gains are lost. This does not

mean that charts should be maintained if their purpose has been replaced by a better quality measurement. It is possible to conclude that a particular process measurement just does not represent the character of the process that is most important. Such a measurement should be abandoned and Stage 2 started over, or it may be necessary to go back to Stage 1 and redefine the system to be analyzed.

Once statistical control is achieved, improvement action needs to be redirected toward common causes of variation (Step 5). Many methods are available for the identification of common causes of variation and they all fall under the headings of problem solving and participative management techniques. Some of these methods include brainstorming, nominal group technique, Ishikawa cause-and-effect diagrams, Pareto charts, fault trees, design of experiments, simulation, quality control circles, and other worker participation programs. Improvements in the process can be achieved in two ways: first, the identification and removal of common causes of variation; and second, the creation of special causes of variation. Actually the removal of a common cause of variation will also show up on the control chart as an out-of-control condition. However, the deliberate introduction of special causes of variation into the process is a form of experimentation. The control charts operate as the barometer of the system to reveal if anything real has happened as a result of the new change. A significant improvement in process performance will appear on the chart as a sustained shift in the process average. As soon as enough data points are collected under the improved system new control limits should be calculated and additional special causes of variation looked for.

This cycle may seem contradictory since the first step is the removal of special causes of variation and this last step may reveal new special causes of variation. This can be explained by using the metaphor of a radio signal being transmitted through a field of static. The set of special and common causes of variation is the field of static or noise through which the signal must pass. As the noise level due to these causes of variation is decreased, a weaker set of special causes of variation will make their appearance.

This improvement effort should be continuous because every cause of variation removed from the process removes a cause of waste and inefficiency. As shown in Chapter 3, productivity improvement is a necessary result of quality improvement.

Three rules given by Price (1984) are a fitting summary for this stage of the implementation process: "1. No inspection or measurement without recording. 2. No recording without analysis. 3. No analysis without action."

Stage 3

The third stage of the implementation process is the propagation of improvement efforts throughout the surrounding activities. It consists of two steps. The first step is a continuation of the last step of Stage 2 because the idea of never-ending improvement is so important. The second step consists of communicating the input quality requirements of the system to the suppliers. A demonstration of the benefits of statistical process control may be all that is necessary to prompt the suppliers to begin the same efforts in their areas. It may be necessary to train the suppliers in the use of statistical process control and walk them through one or two improvement activities

to convince them that the effort is worth continuing. Any assistance given the supplier in this effort will be a valuable investment because significant productivity improvements can be realized if the quality of all input resources is consistantly high. The most apparent improvement would be the elimination of the need to inspect incoming resources.

CHAPTER 6
Case Study:
A United States Air Force Civil Engineering Squadron

This case study will begin with the sequential application of the steps described in chapter 5 to a single work process. Recall that some steps can be conducted concurrently. At other times it may be necessary to go through a sequence of steps several times before moving on to the next step. The following account will serve to demonstrate some of the thinking processes that must occur at each step rather than trying to consider all possible contingencies. Each step will be kept separate and distinct from the others by labeling each step as it begins. There will be occasions when more than one iteration through a series of steps will be required. In such a case each step will only be labeled in the first iteration. Subsequent iterations will not have labeled steps. Actual examples will be used in most cases. However, the steps that require policy change or the extensive involvement of the managers will be dealt with in a hypothetical manner. This is necessary because the organization being studied did not commit resources to the fault diagnosis process nor did they make any committment to identify and implement possible changes to their processes.

Due to the nature of the first part of this chapter only a limited number of the contingencies possible in the implementation of statistical process control can be addressed. Therefore, the last portion of the chapter will present in somewhat less detail several other cases from within the same organization. These will illustrate a few additional aspects of the implementation process.

A United States Air Force civil engineering squadron was selected for this case study. This organization was selected for two reasons. First, the author has a direct working knowledge of a civil engineering squadron's operations. Second, a large amount of the work performed by a civil engineering squadron is in the category of support operations.

Stage 1--The System

To set the stage for the application of statistical process control it is necessary to have a basic understanding of the unit's mission and its organization. Of course, this is something a manager should already understand, but this knowledge should not be taken for granted since it is essential to the success of a quality improvement program.

The civil engineering squadron on a United States Air Force base is responsible for the acquisition and maintenance of all the installation's real property facilities. This includes land, pavements, structures, and public utilities. A large portion of the squadron's [illegible] is taken up in administration. Being constrained by annual budget limitations, it is necessary to carefully evaluate every request for maintenance, modification, and new construction. The motivation is to insure that adequate funding is available throughout the fiscal year so that the primary mission of the base is not jeopardized due to lack of maintenance or insufficient support facilities. Specific regulations govern the use of these funds by designating certain amounts for specific purposes. The civil engineering squadron also prepares requests for Congressional appropriations needed for the acquisition of large facilities.

The operations branch is responsible for all aspects of the delivery of the service to the customer. Although the actual work or service provided by the squadron is performed by individual craftsmen in the shops, the administrative support activities are largely responsible for the efficiency of the organization, whether this be the organization's actual efficiency or the customer's perception of its efficiency. The control point for most of a civil engineering squadron's administrative support activities is the production control section. This section is part of the operations branch. In addition to production control it consists of the following functions: customer service and the service call desk, programming, and scheduling. The production control function is the hub of most of the information flow in the squadron. It not only coordinates the activities within the section, it also controls the flow of information to other sections within the operations branch and the rest of the squadron. Figure 8 shows where the operations branch and the production control section fit in the overall organization of the squadron. Figure 9 diagrams the relationships between the various functions within the operations branch and between the branch and its immediate external environment.

There may be some confusion over the use of the word "customer" so a brief note is warranted. The obvious customer is the person or unit that receives the work performed by the craftsmen. In most instances this will be clear without any special treatment, but if ambiguity is possible the term external customer will be used. Another type of customer that will be referred to is one that is

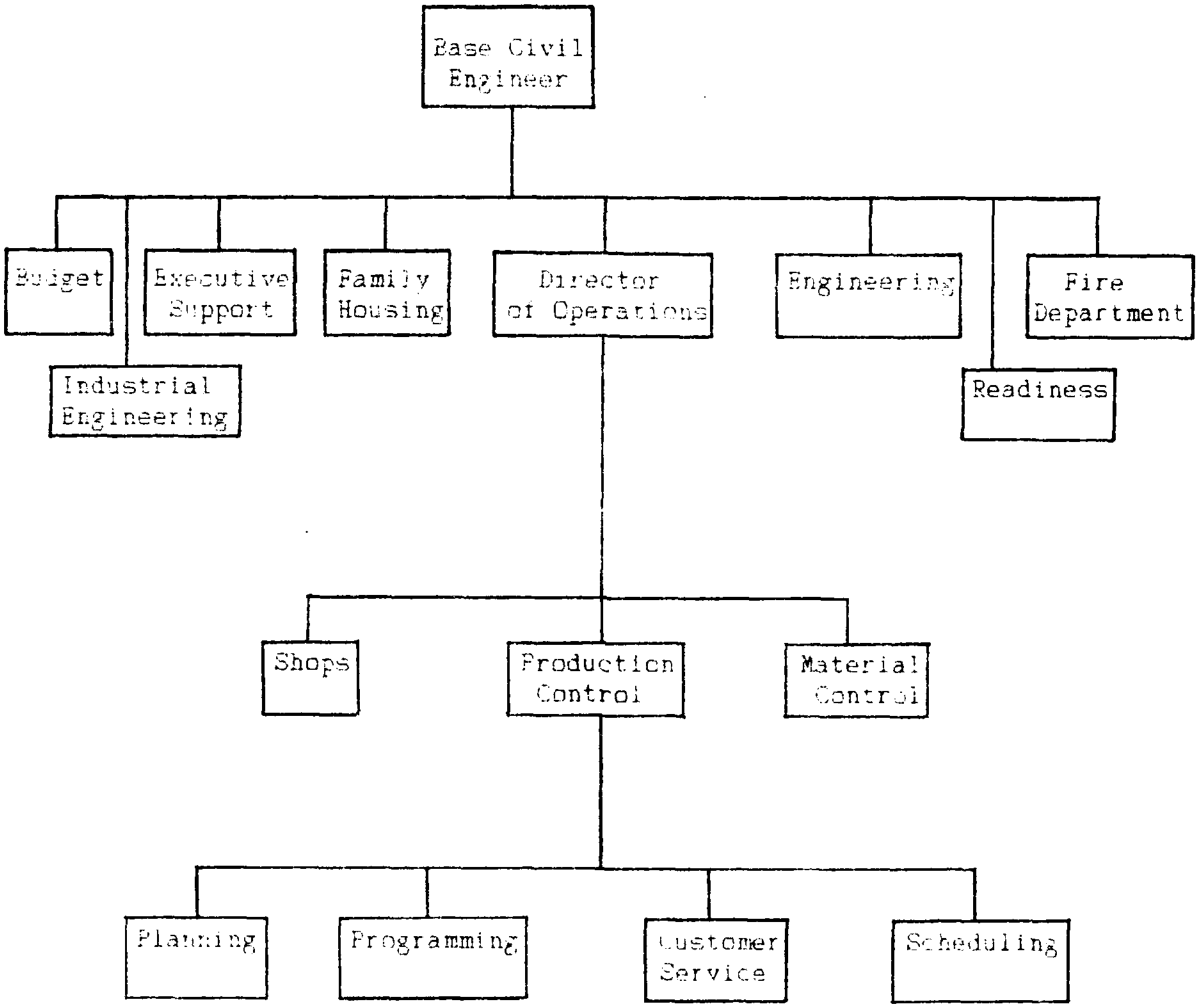


Figure 8
Civil Engineering Organization

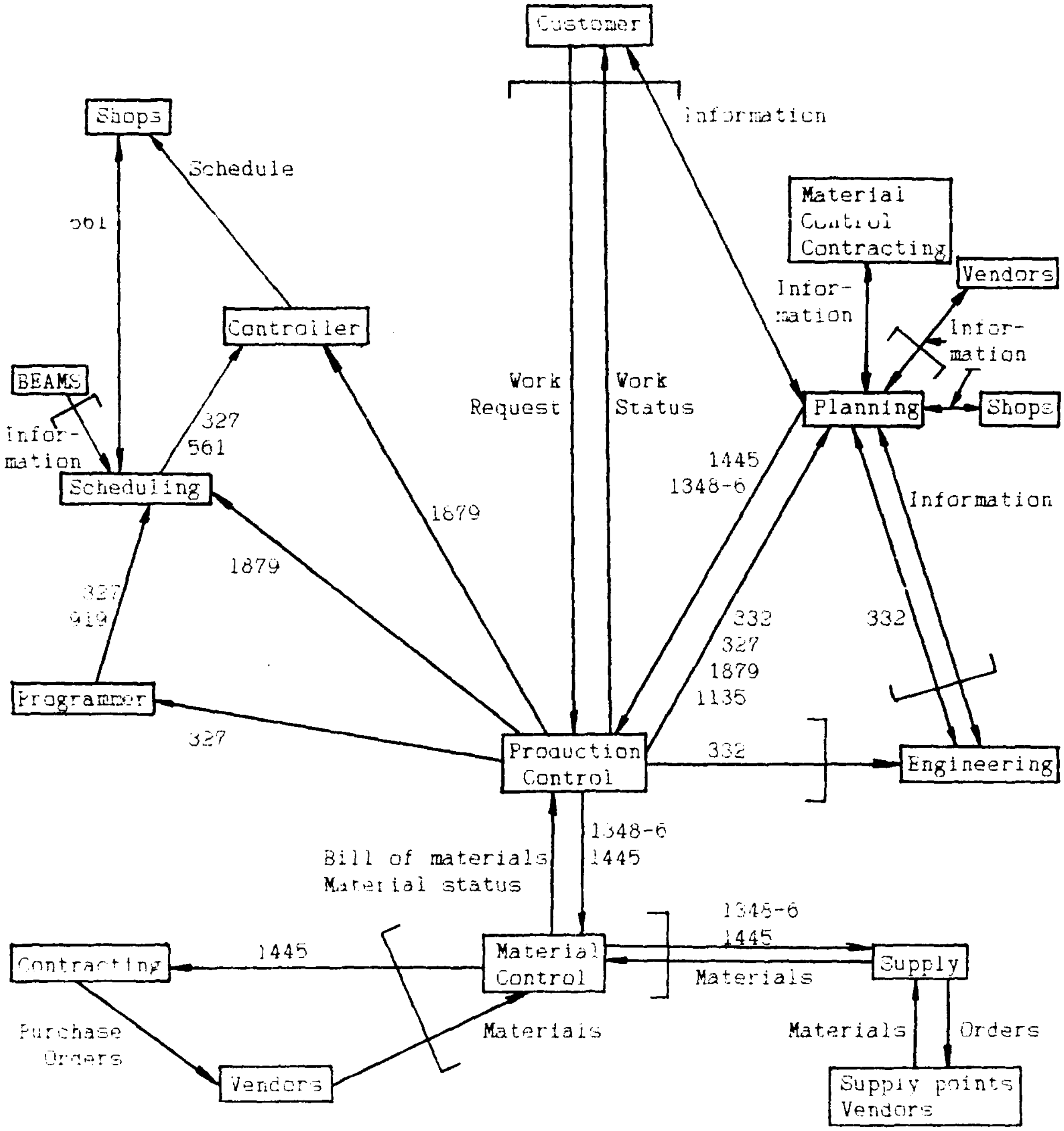


Figure 9
Operations Branch Work Processing System
with Boundaries

internal to the organization so the term internal customer will be used in this case.

Step 1--Select the system.

The operations branch was selected since it manages most of the activities involved in the delivery of service to the customer including a major portion of the support activities. It handles a large volume of work and maintains a direct working relationship with many other functions, not only those within the squadron but also with functions outside the squadron. It is also large enough to include several complete processes.

Step 2--Identify the boundries.

The boundaries around the operations branch are shown in Figure 9 as a bracket across the flow line(s) between entities. They are drawn so that every function under the management of the Chief of Operations is contained inside.

Step 3--Identify the flow across the boundaries.

Figure 9 also shows the flow across the boundaries of the operations branch. This flow consists of information in most cases. There are only two exceptions. Part of the exchange between the shops and the external customer consists of physical labor, and part of the exchange between material control and supply consists of materials. In all other cases information is the raw material and the finished product; and the transformation of this information is the work process. Note that in some cases the information takes the form of spoken word either delivered in person or by telephone, and in other cases the information comes in written form. In any case the quality

of this information will have a direct impact on the efficient operation of the rest of the squadron.

Step 4--Define who your suppliers are and who your customers are.

This must be done for each activity. Many of the exchanges are two-way. In other words, the roles of customer and supplier switch depending on the direction of the exchange. For example, when an Air Force Form 1445, Purchase Request, is sent to material control, material control is the customer of production control. However, when material control sends a bill of materials to production control they become production control's supplier.

In order to narrow the scope of discussion at this point, one specific activity will be selected to serve as the focus of discussion. This activity will be the processing of job orders. This is a fertile area for study because it comprises the largest volume of work performed by the squadron and it is the source of many customer complaints. Improvements in this area will be easily recognized as increases in both actual and perceived quality and operational efficiency.

The raw material for this activity comes from the external customer in the form of a request for work. Several means are available for the customer to communicate this request. This information is processed by the operations branch and the final product is delivered to the external customer in the form of work performed by the shop. It is interesting to note that the external customer acts both as the initial supplier of raw material and as the ultimate recipient of the product. This is the case in many service operations, that the initial supplier is also the ultimate user (Baker and Artinian, 1985).

The job order form, Air Force Form 1879, is produced by production control using the information supplied by the external customer. After processing this information the job order could go to one of two units. It could go directly to the shop for them to do the work; or, if the job is sufficiently complex, the form would go to planning first before going to the shops. If the request for work is not authorized it will be returned to the requestor with an explanation. The internal customer of production control for this process is either the shops, planning, or the external customer again.

When the shops finish a job, the job order form is returned to production control with additional information. Production control processes this information for accounting purposes and stores the form for historical record. In this particular process the shops are the suppliers and the accounting system is the customer. Anyone who needs the historical information stored in the file is also a customer.

Step 5--Operationally define your quality requirements for incoming resources.

The incoming resource is the information from the requestor about the work that needs to be performed. The quality requirements for this information are given in the form of a checklist as shown in Table 3. This checklist is used by the individual at the customer service desk at the time a request is made. Its purpose is to insure that the correct information is received and that this information is complete.

There is a variety of information on the job order form that is entered by the customer service specialist at the time the request is made. Some of this information identifies the work requestor and some

Table 3
Customer Service Checklist

1. Name and Grade of Requestor.

2. Is the requestor the facility manager?

3. Building number and address. If the work is outside get a complete description of its location.

4. Room number or location inside the building where the work is required.

5. Requestor's office location, phone number, and alternate point of contact.

6. Get a complete description of the work that is required.

a. Is it a repair, maintenance, or a new requirement?

b. Is the nature of the problem clearly evident to the requestor or does the requestor merely observe a symptom the of the problem?

c. If it is a symptom, can the requestor surmise what the real problem might be? Ask the following leading questions if appropriate:

--If the symptom is a leak, is the leak water or some other substance. Is the leak from the ceiling or from the wall or floor? Could the leak be due to a roofing, plumbing, or air conditioning problem?

--If the symptom is a noise, is it due to an electric motor, fan, air conditioning compressor, appliance, steam lines, or heating unit?

--If the symptom is simply that an item will not function get the requestor to describe what has been done in any attempt to make it work.

d. What is the extent of the problem? For example, how much of an area is involved? How many units are inoperable? Are there any backup systems? How does the problem effect the unit's operation?

7. Assign a job order number, job priority, and estimate job completion time, and give this information to the requestor

8. Place the job order form in the appropriate zone box or route it to planning through production control.

identifies the work to be done. The shops and/or planning, the internal customers of this process, need this information to be complete and accurate. Effort is wasted if the craftsman has to visit the work site to learn something about the job that could have been obtained from the requestor at the time the request was made.

Step 6--Define or obtain your customer's quality requirements for your outgoing resources.

There are two aspects of the work that define the quality requirements of the external customer. The first is that the physical results of the work be satisfactory. This is difficult to define operationally because it depends on the type of work that is performed. In some cases it may be the appearance that is important to the customer and in other cases just the fact that the item operates is sufficient.

The second aspect of quality of concern to the customer is the response time. In most cases the customer is satisfied if the work is done when promised. At the time the request is made the customer service specialist gives the customer an estimate of when he can expect the work to be accomplished. This estimate is based on the priority of the work as judged by the customer service specialist. There are three priorities: emergency, urgent, and routine. The response time for each priority is mandated by regulation. Emergency jobs must be completed within one day of initial request. Urgent jobs must be completed within five days and routine jobs within 30 days.

The time the request is made is entered on the form by the customer service specialist and the time that the work is completed is entered by the shop foreman or craftsman. The time lapse is monitored

by production control and all jobs that have not been completed in the prescribed time are classified as delinquent and are reported to management.

Step 7--Describe the sequence of operations.

Figure 10 gives a diagram of the job order process flow. The process begins with a work request by an external customer. This information is processed by production control. The job order form is filled out by the customer service specialist who received the request. The information obtained from the external customer consists of the following: name, location, and phone number of the requestor; description of the required work including its location, the nature of the work to be performed; the size of the job; and the type of materials required. If the work is not authorized the customer service specialist may be able to determine this immediately or it may be returned to the requestor at a later date after review by a higher official to determine authorization.

The customer service specialist assigns an identification number to the job order, determines the job priority, and informs the external customer when he can expect the work to be accomplished. The customer service specialist then estimates the time it will take the shop to do the job and the size of crew required. He also decides whether the request requires additional planning. A job order log is maintained to insure all requests are responded to in a timely manner.

Here the process flow can go directly to the shop or take a detour through planning. If it goes directly to the shop, the shop foreman takes note of the job priority and makes the assignment accordingly. The foreman has control over when the job is started,

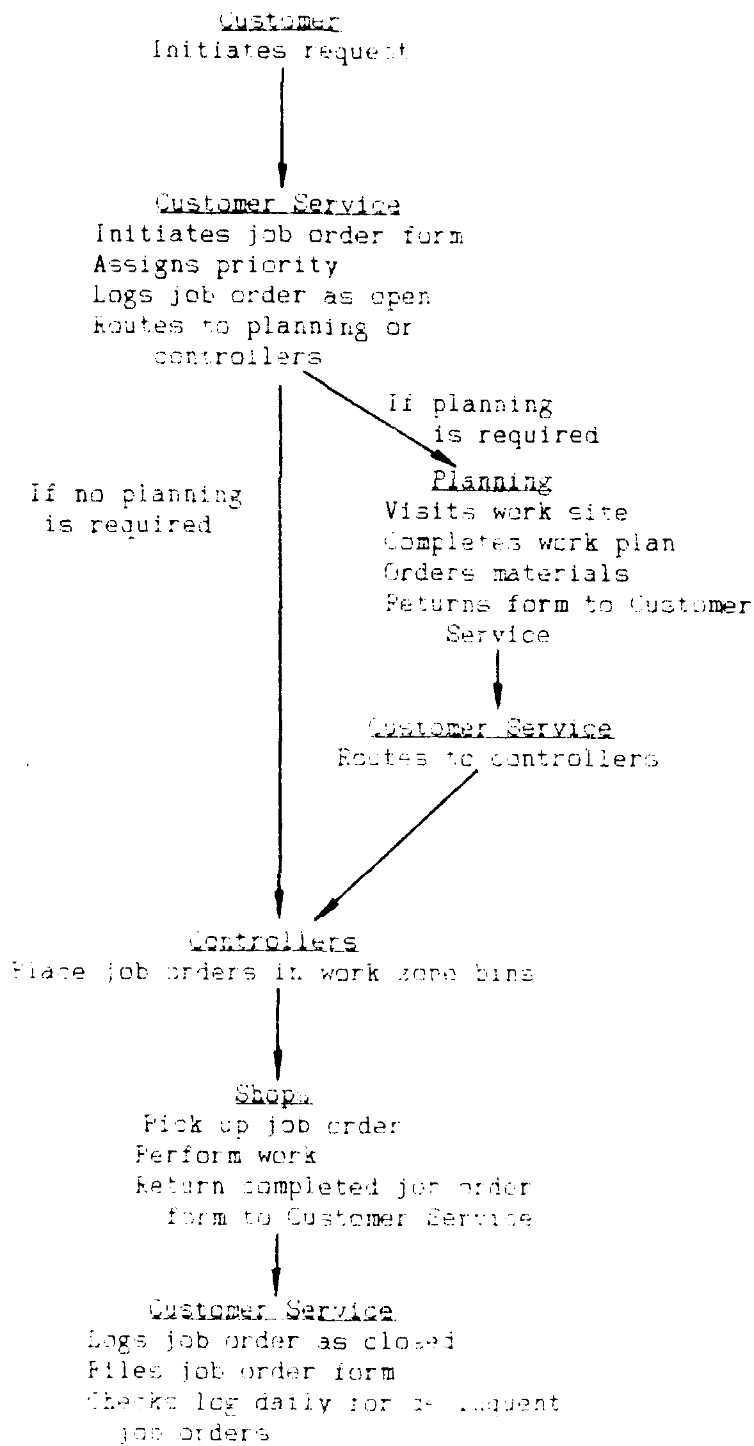


Figure 1[illegible]
Flow Diagram of Job Order Process

but there are several causes that may delay a job's completion that are not within the foreman's control.

The job order form is given to the craftsman when he is assigned the job. The craftsman visits the job site with the tools, materials, and assistance he considers necessary based on the job order and his past experience with the facility that he will be working on. The craftsman makes contact with the job requestor, is shown the job site, and they discuss job details. At this point the craftsman may begin the job or he may need to return to the shop for additional materials or tools. For small jobs it is expected that the craftsman may need to return to the shop before beginning the work because the craftsman also plays the part of the planner. This may, however, cause a delay in job completion because the required materials may not be on hand.

If the job order is detoured through planning it means that detailed planning is required to completely evaluate the requirements of the job. The Chief of Planning will assign the job order to a planner based on the job priority and the planner's current work load. The planner visits the worksite and determines the type and amount of materials required to do the job. The plan will also include the method of accomplishment deemed most appropriate by the planner. The required materials will be ordered and the job order will be sent back to production control for routing to the shops when all the materials are received by the material control section.

When a job is finished the craftsman has the job order signed by the requestor affirming that the work was completed and records the time and date of completion. The craftsman turns the job order form back to the foreman who reviews it and sends it to production control.

Production control records the cost information in the accounting system and files the form for future reference. Production control also monitors the status of uncompleted job orders and keeps a record of all those that are delinquent. This information is made available to top management and the external customer is kept apprised of the situation.

This ends Stage 1. It provides the information about the operating environment that is necessary to understand the process in statistical terms and apply the techniques of statistical process control.

Stage 2--Apply statistical process control to the process.
Step 1---Collect data on the process.

The first thing a manager has to do is choose the measurements to be used. Any measurement of process performance will behave in a statistical manner and be amenable to the concepts and techniques of statistical process control. *The measurements chosen, however, will have* a direct influence on the quality of the process information received through the use of statistical process control. It is important to choose process measurements that have a direct relationship to the customer's quality requirements. This may not be known at first but the preliminary processing of the data and the act of applying statistical process control refines the understanding of the process and may prompt a change in process measurements.

It is a good idea to begin with a measurement that is already being taken. There are two main advantages to this approach and one important disadvantage. First, the data is readily available. This makes it easy to establish a process history against which present performance as well as the effects of any process changes can be com-

pared. Second, a new task will not have to be added to the normal operations that may impede the implementation of statistical process control. The introduction of a new process measurement may also require someone to perform an additional task that may not be needed. The disadvantage is that existing data is usually not collected in a manner consistent with the requirements of statistical process control. In other words, process sampling may be irrational and/or the output could be from a mixture of processes. Dr. Deming (1982) offered a sound piece of advice on this matter. "There is too much talk of the need for new machinery and automation. Most people have not learned to use what they have." His statement is directed toward the acquisition of new capital equipment but it is also applicable to the acquisition of anything new. There is a lot of information available in current measurements that is not being used. Statistical process control is a way to learn how to get the most information out of available data. First a preliminary analysis of the available data will be conducted.

Preliminary Analysis

In the case of job order processing, the duration between the job request and the time the job was completed is of special concern to management. This information is available in two forms. A summary of delinquent job orders by job priority is presented to management once a week. This summary gives the number of routine, urgent, and emergency job orders that were delinquent at that time. It may also include some details about jobs that are of particular interest to management. This data can be considered to be the number of defects found of three different types during a week's worth of work. This is

analogous to counting the number and types of defects on a molded plastic part. Since this is an attribute measurement a c-chart for number of defects would be most appropriate.

Another form this information is available in comes from the individual job order forms. Each form contains the job priority, the time the request was made, and when the job was completed. The measurement of interest is the time lapse between the time the request was made and the time the work was completed. More work is required to extract this information in a usable form but it provides more information about the process so the extra work is justified. This is a variable measurement so X-bar and R-charts can also be used. The unit of time used for this measurement was "day". If a job was completed on the same day it was requested, the duration would be zero. If it was completed the next day the duration would be one.

The data sample consisted of all the job orders completed each day and the information was recorded consecutively according to the day it was completed. The following information was collected from each job order: the job order identification number, job priority, the shop to which the job order was assigned, the date received, and the date the job was finished. The time lapse was calculated by subtracting the date received from the date completed.

Bar charts and Pareto charts were constructed as shown in Figures 11 through 16 to give a better understanding of the data and how it was distributed.

Figure 11 shows ths distribution of job orders by priority. Notice that the majority of the job orders are urgent and that routine job orders comprise a very small percentage of the work. Therefore,

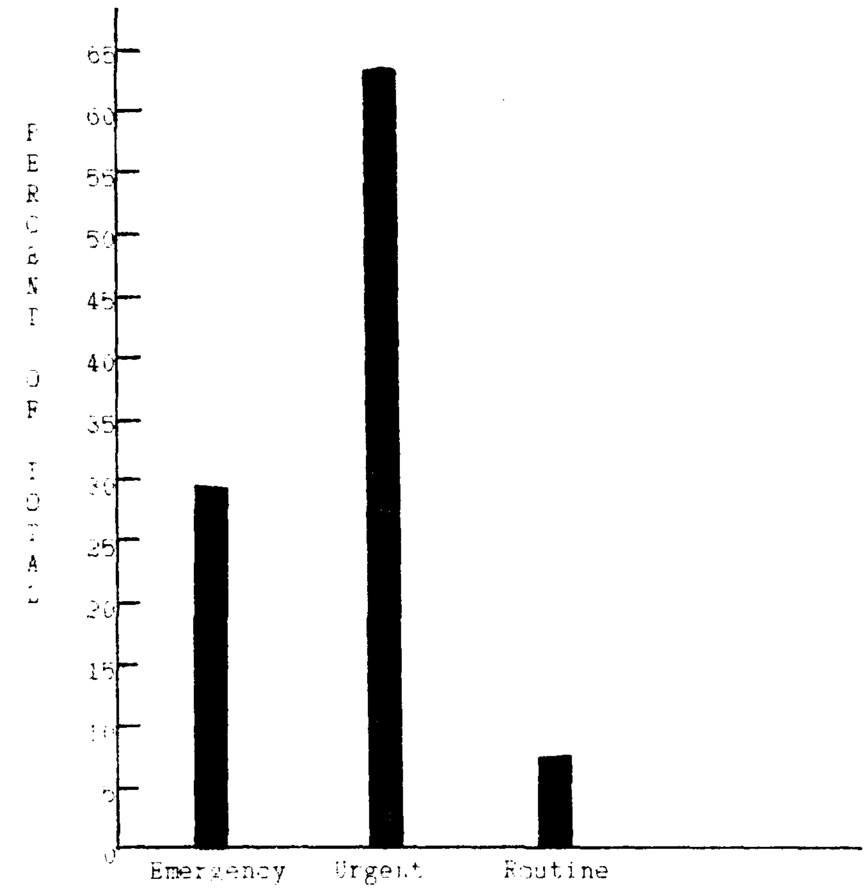


Figure 11
Distribution of Job Orders by Priority

it is reasonable to ignore the routine job orders at the beginning and concentrate all analysis efforts on urgent and emergency job orders.

Each shop exists as a separate processing system so they should be analysed separately. Shops differ in a number of significant ways that would hopelessly confound the data if their production streams were combined. One difference is that each shop does a different type of work. Some shops have many simple repair jobs while other shops have more complex repair jobs. The plumbing shop, for example, gets a high volume of calls to unplug toilets and fix leaky faucets. For the most part these jobs require little diagnostic activity and can be completed in a short period of time. The refrigeration shop, on the other hand, receives a large number of calls to repair units that are reported to be not working correctly. A large portion of the craftsman's activity is involved in diagnosing the problem. Once the problem is tentatively identified, replacement parts may have to be picked up at the shop or ordered through material control. The craftsman then tries out his solution to the problem. If he has diagnosed the problem incorrectly the process will have to be repeated.

Figure 12 shows the average response time for emergency and urgent job orders for all shops. A visual inspection of this chart serves to confirm our belief that each shop generates a unique stream of response time data. Eleven shops are included on this chart and each is identified by a three digit code. The meaning of these codes will be explained shorty once the field of interest have been reduced. The "Other" category includes five shops that rarely receive job orders of any kind.

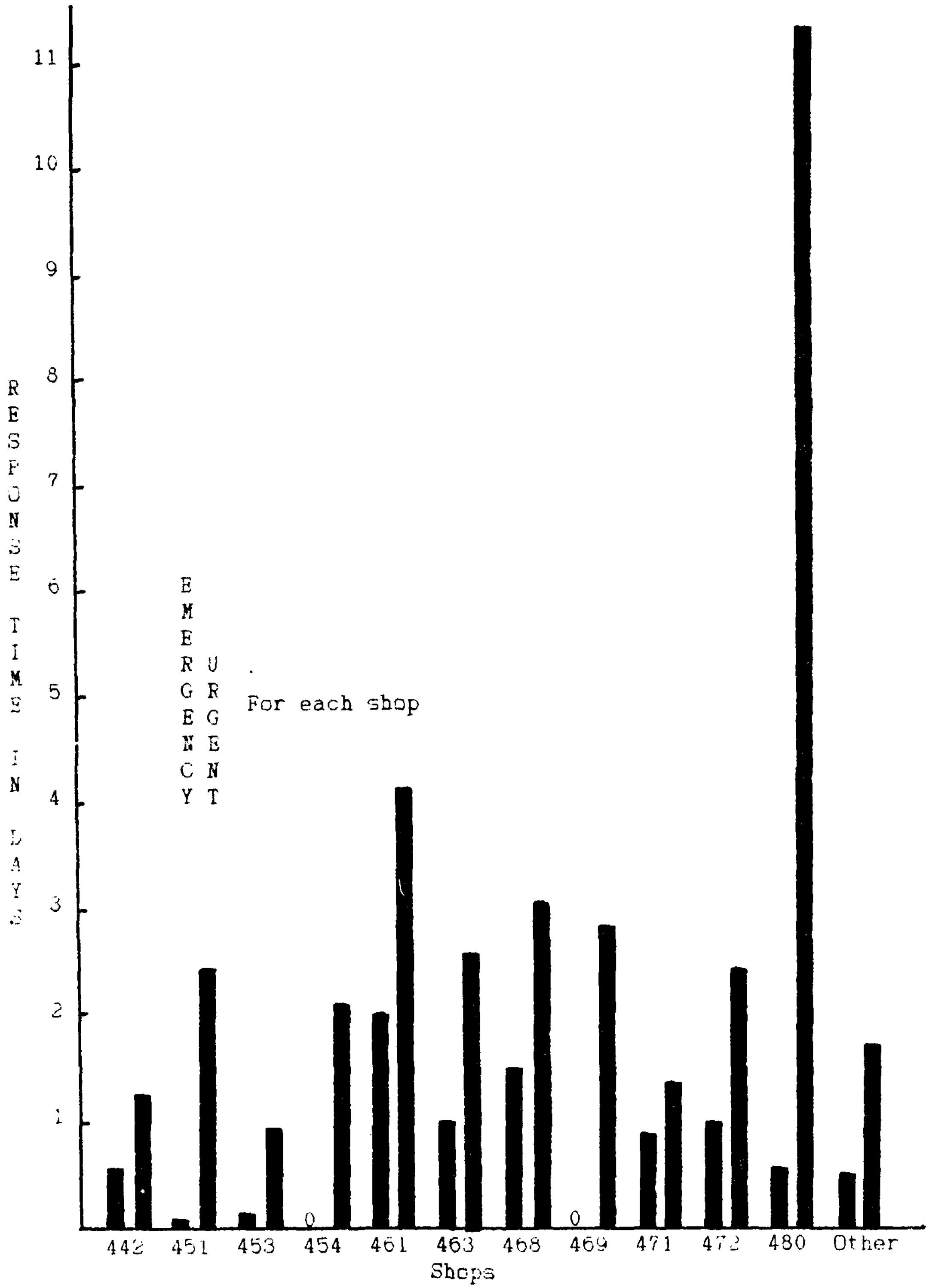


Figure 12
Average Response Time for Emergency and Urgent Job Orders

It is also true that some shops have a higher volume of job order calls than others and that some shops will have a higher concentration of emergency calls while others will have higher concentrations of urgent or routine calls. Figure 13 shows the distribution of job orders by shop and by priority.

Instead of analyzing all of the shops just those which carry the largest volume of work were selected. The Pareto charts in Figures 14 and 15 were used to make this choice. Figure 14 shows the distribution of emergency job orders for each shop and Figure 15 shows the distribution of urgent job orders. The shops are listed in order from the one with the highest percentage to the one with the lowest. Notice that the sequence on the emergency job order chart is different from the sequence on the urgent job order chart. However, by analyzing the following five shops, 451, 453, 463, 468, 471, over 87 percent of the urgent job order volume and over 70 percent of the emergency job order volume would be included.

A similar chart was constructed for routine job orders to be used for future reference. See Figure 16. Notice on this chart that the majority of the routine job orders are received by four of the shops. In fact, it would be reasonable to begin an analysis on shop 451 alone since it receives more than 50 percent of the routine job orders.

Step 2--Analyze the data using appropriate control charts.

The five shops listed above were selected for further analysis. Shop 451 is the carpenter shop, 453 is the plumbing shop, 463 is the refrigeration shop, 468 is the heating shop, and 471 is the interior electric shop. Two X-bar and R-charts were constructed for each of

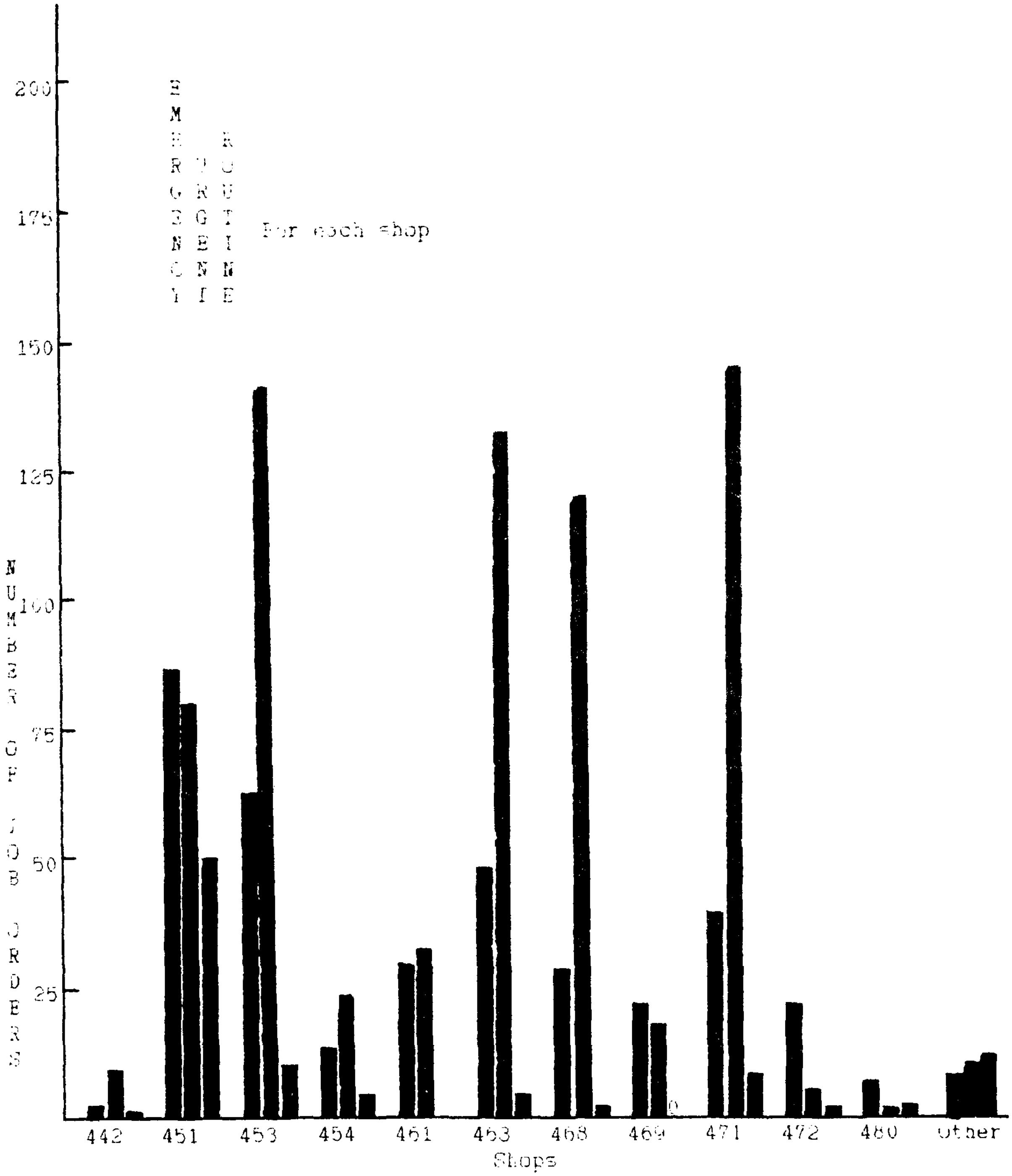


Figure 13
Distribution of Job Orders by Shop and Priority

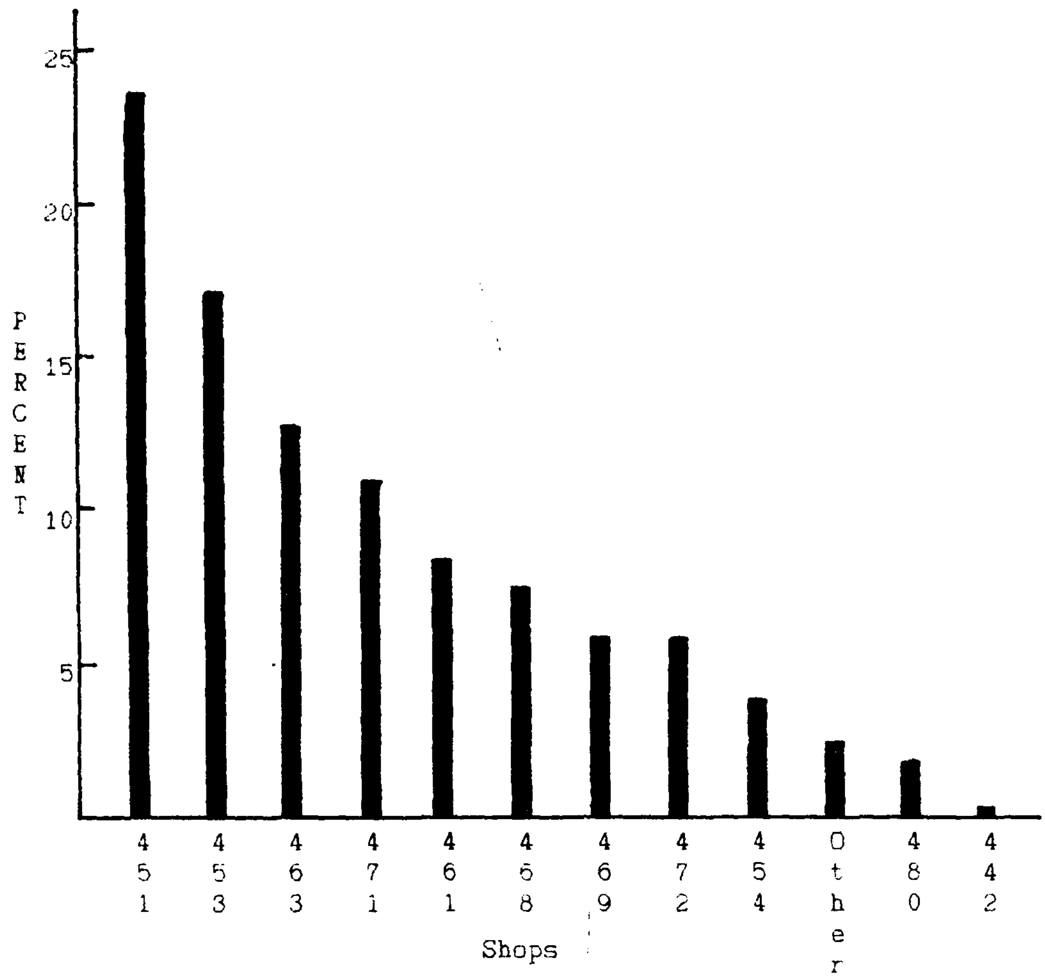


Figure 14
Emergency Job Order Distribution by Shop

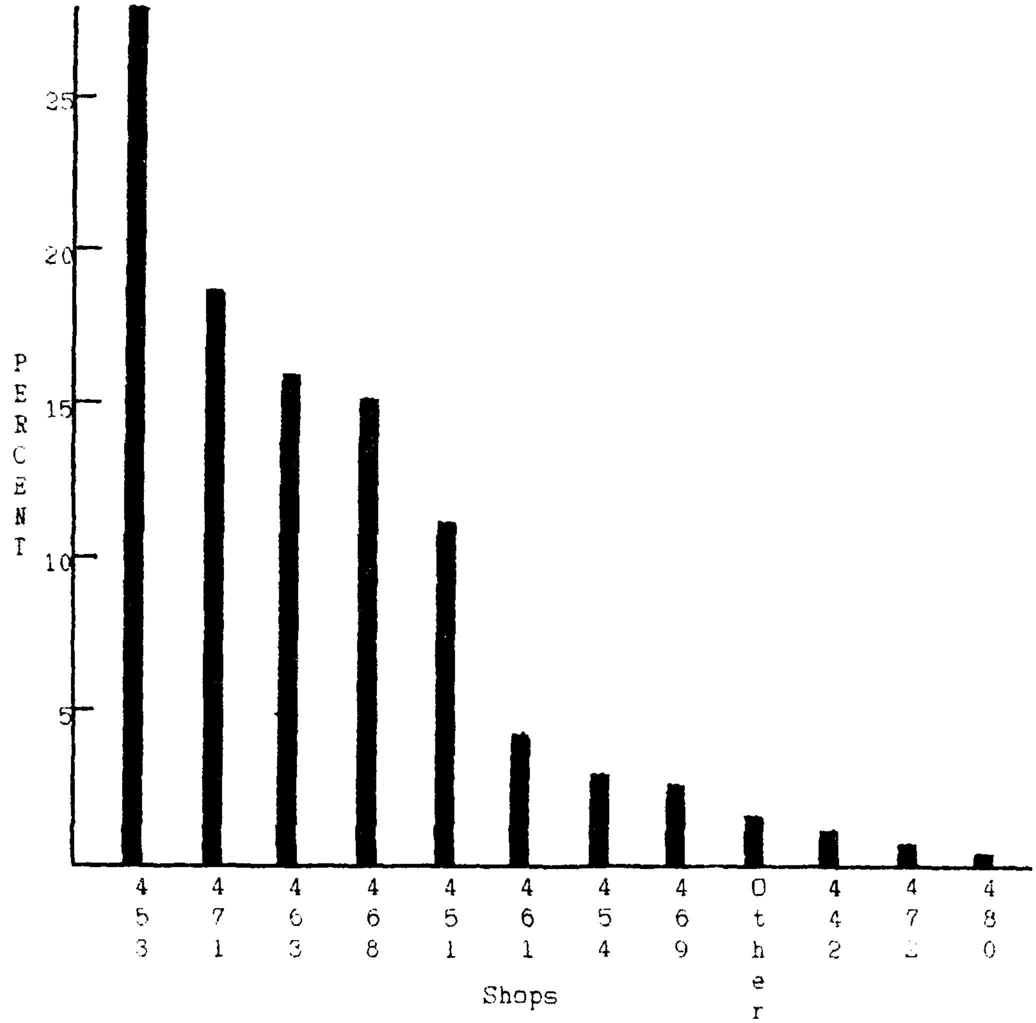


Figure 15
Urgent Job Order Distribution by Shop

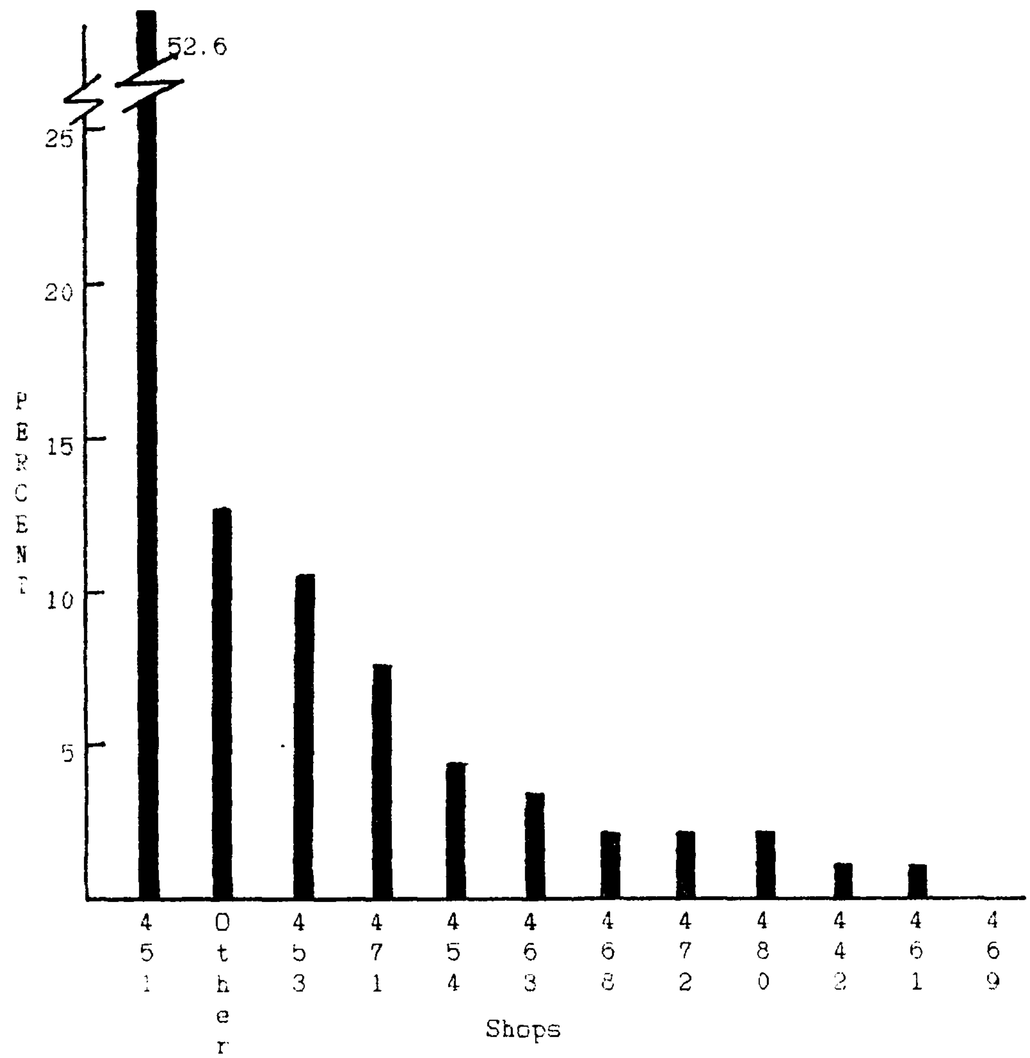


Figure 16
Routine Job Order Distribution by Shop

these five shops using existing data--one chart for emergency and another for urgent job orders. These are shown in Figures 17 through 22. Not enough data existed to adequately analyze the emergency response time for four of these shops (shops 453, 463, 468, and 471) so these charts are omitted.

Each point on the chart represents four job orders completed in one day or over two or more consecutive days. None of the charts indicate that the processes are in statistical control. In other words, one or more special causes of variation are active in each of these processes. It is possible to identify and remove these causes of variation to provide more stable performance. It would be a process performance with less variation, higher quality, and better productivity.

Notice that the lower control limits on all the X-bar charts are less than or equal to zero. There are several reasons for this to occur. The main reason is that the lower control limit was calculated to be less than zero and this was meaningless since all the data is constrained to be greater than or equal to zero. This introduces some unnatural behavior into the control chart analysis. Another reason is due to the roughness of the measurement. Data accuracy is limited to the nearest unit value, i.e., days. This hides some of the natural variation in the process. Measurements made in units of hours would be more amenable to control chart analysis. A third reason is due to the process not being in statistical control. Excess variation in the process will cause the control limits on the X-bar chart to be too wide causing the lower limit to extend below zero. One final reason can be demonstrated in the control charts in Figures 20 and 22. There

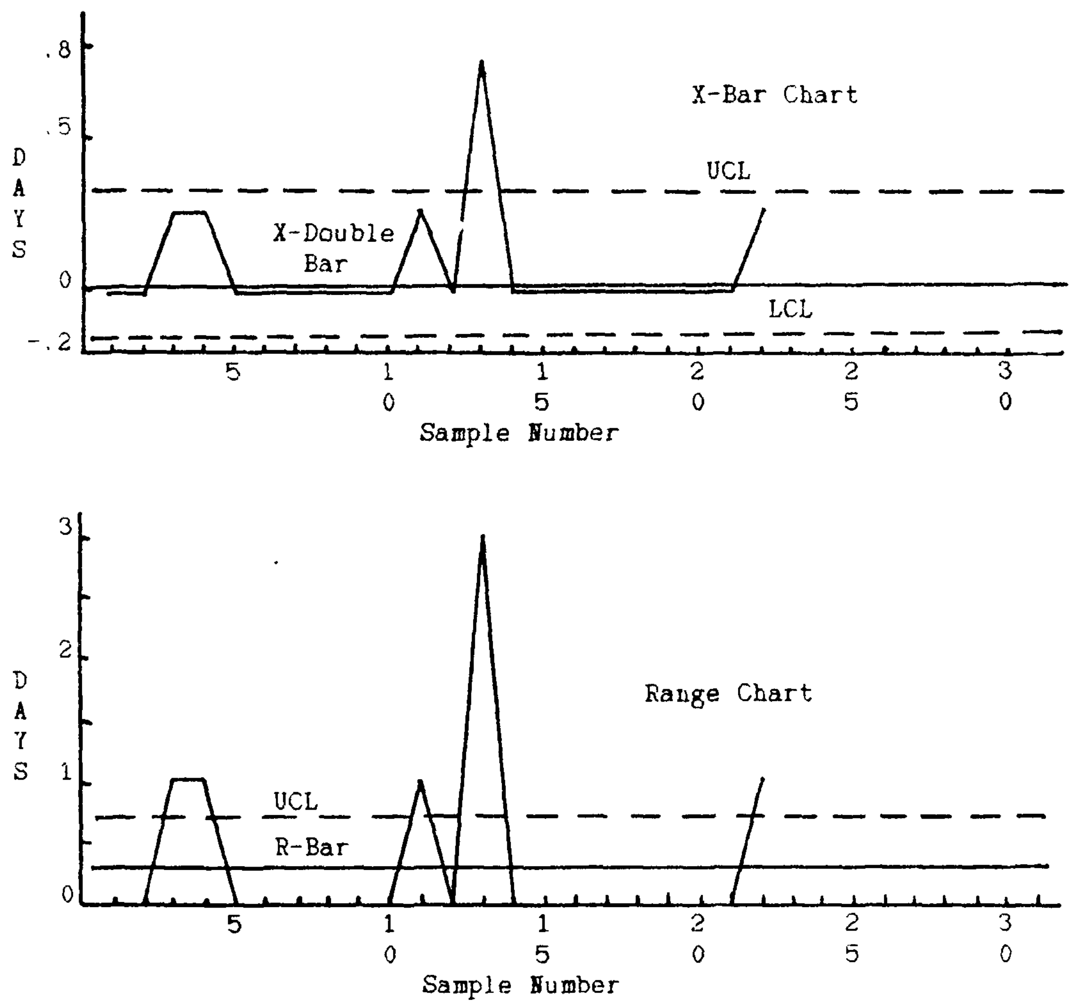
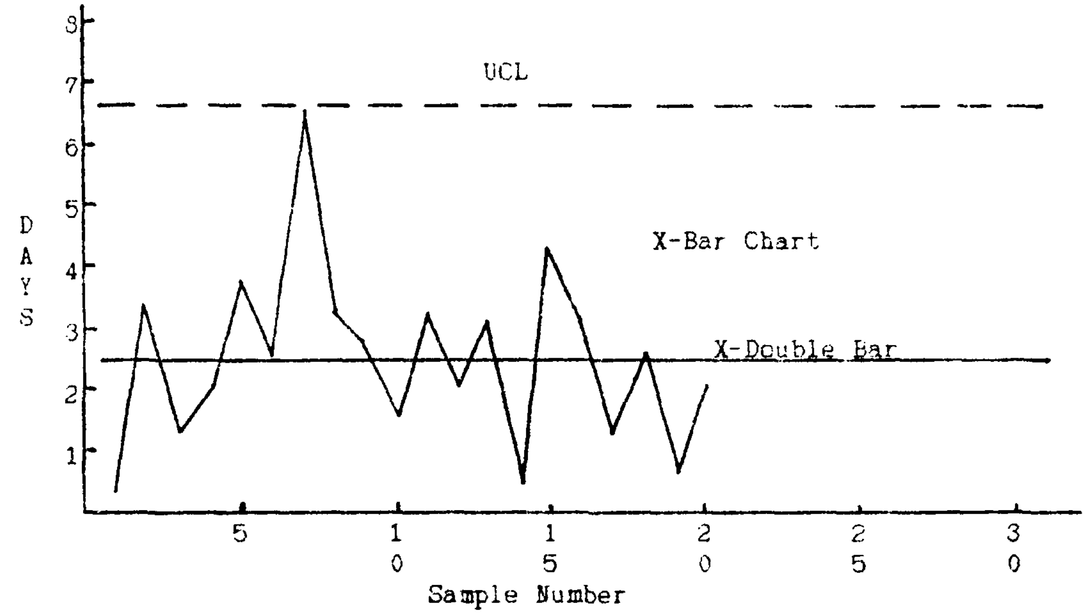


Figure 17
Emergency Job Order Response
Time for Shop 451



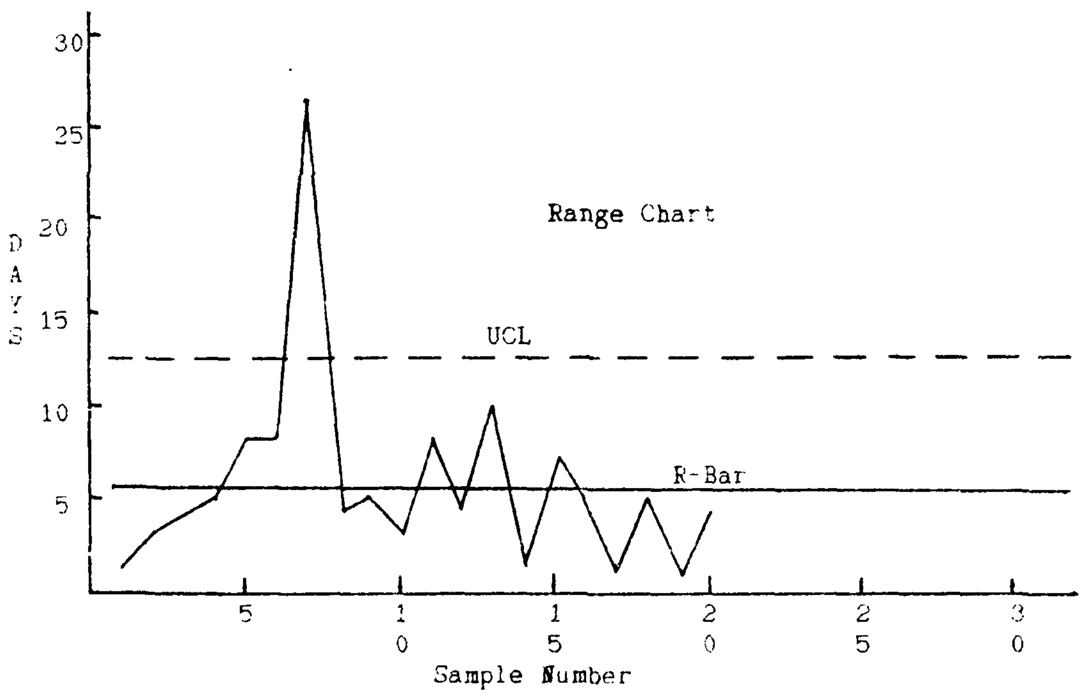
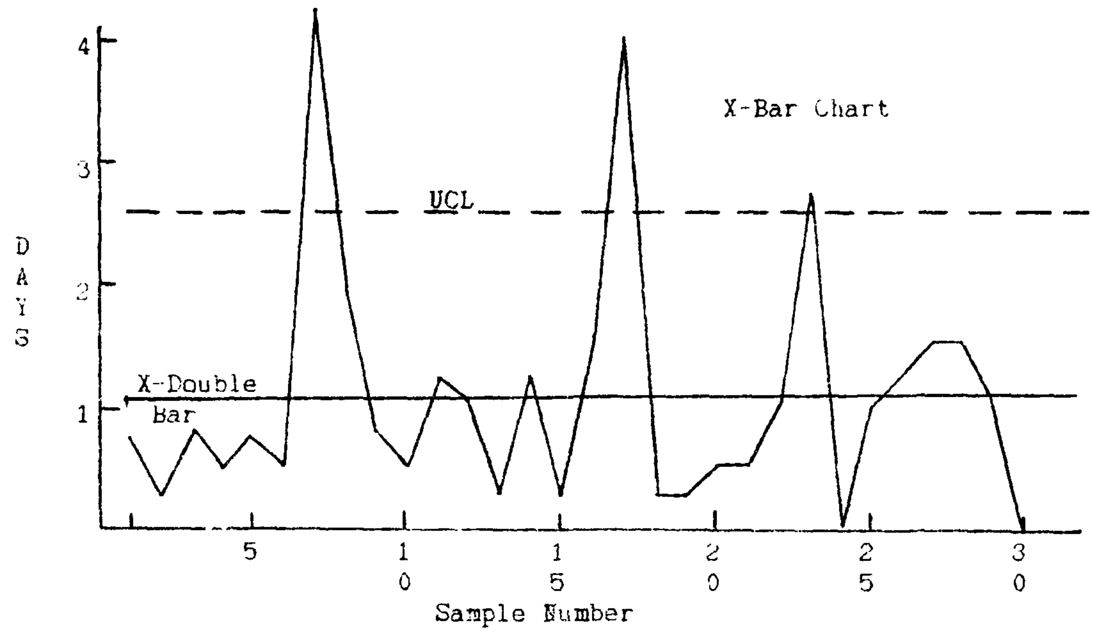


Figure 18
Urgent Job Order Response
Time for Shop 451



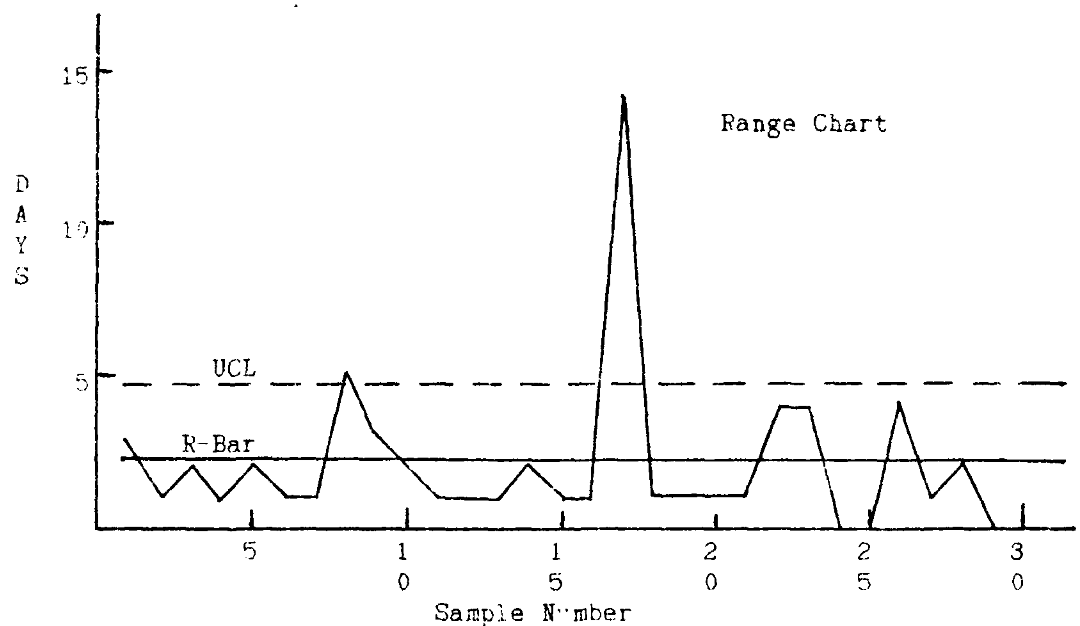
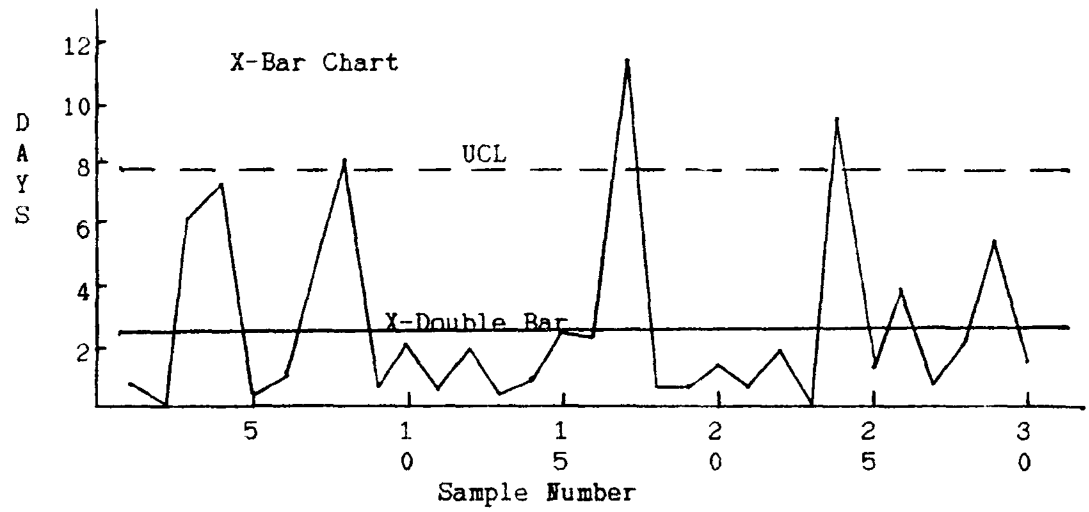


Figure 19
Urgent Job Order Response
Time for Shop 453



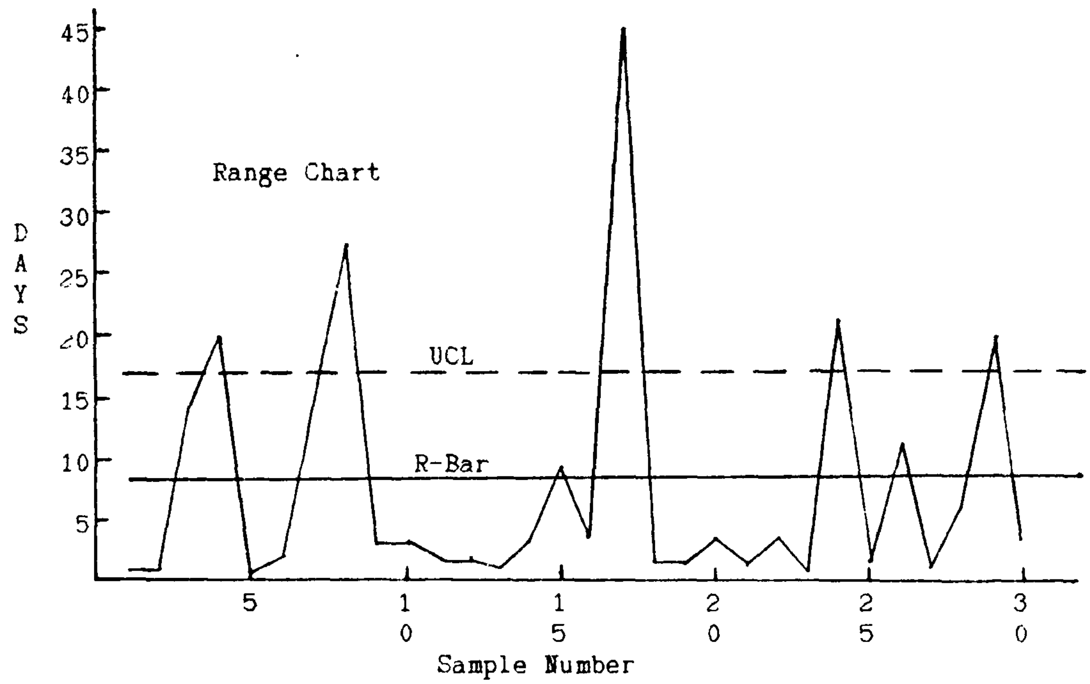
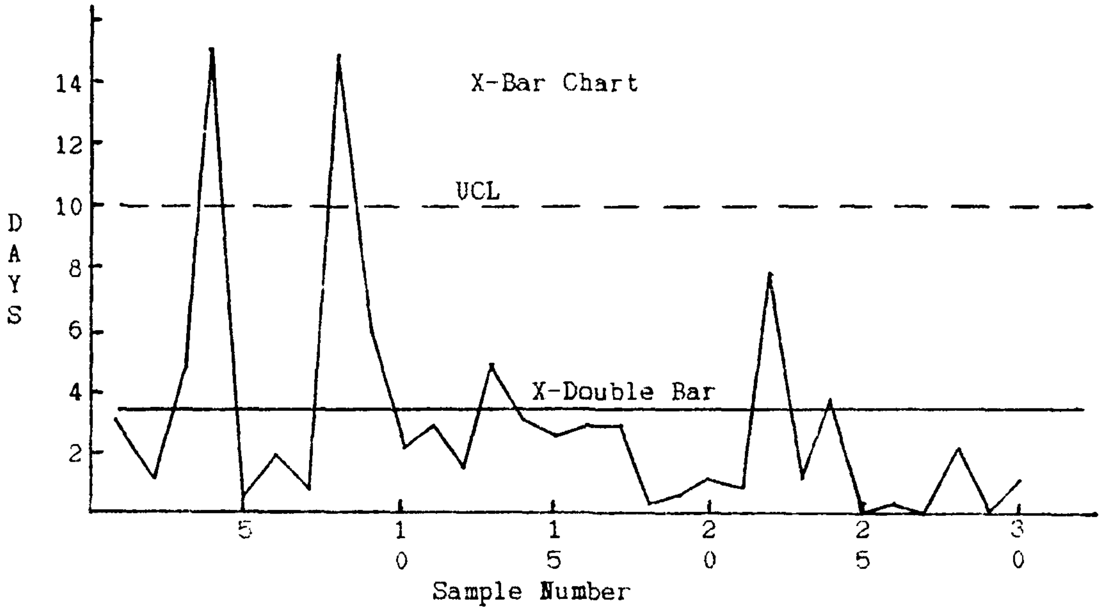


Figure 20
Urgent Job Order Response
Time for Shop 463



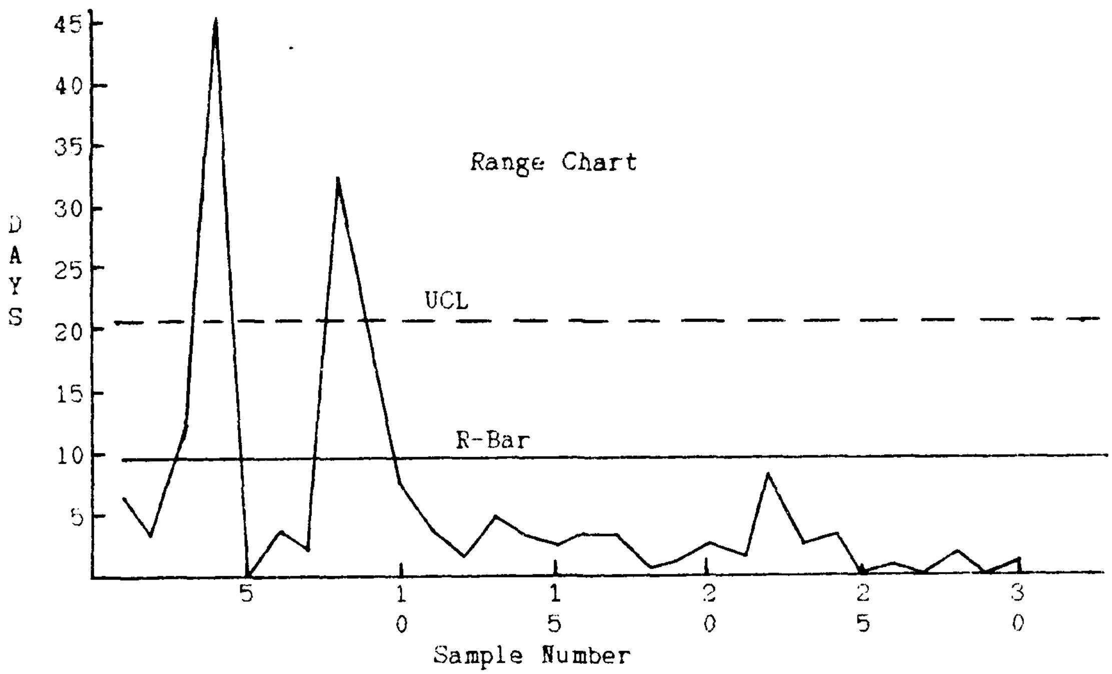
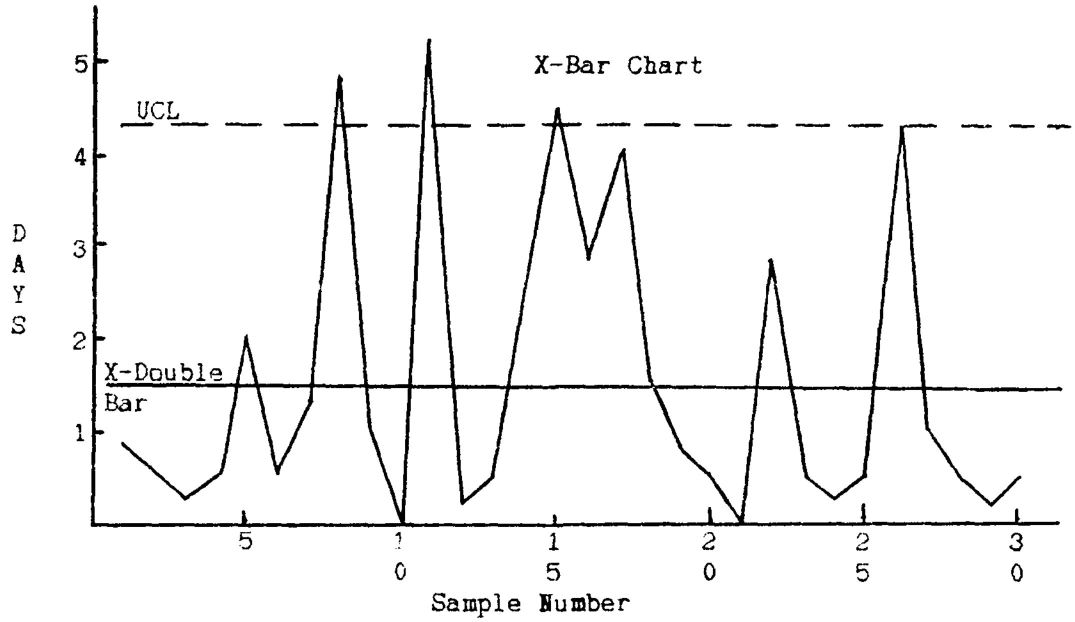


Figure 21
Urgent Job Order Response
Time for Shop 468



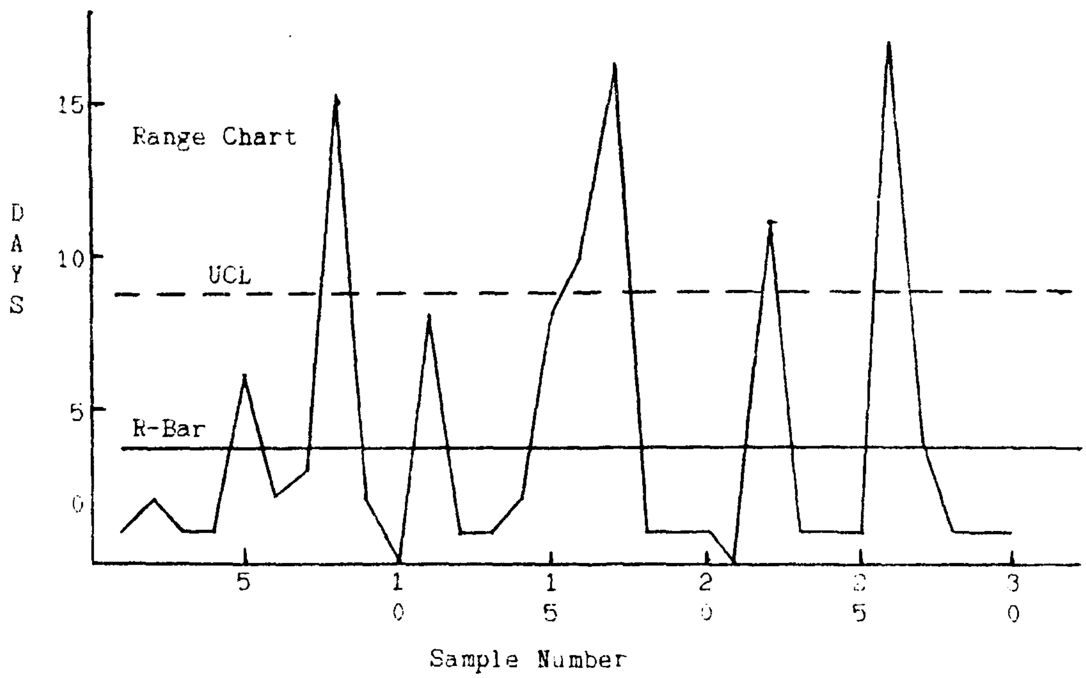


Figure 22
Urgent Job Order Response
Time for Shop 471

appears to be at least two data populations in each of these processes--one data population due to a set of causes that produces excessively long response times, and another population due to a set of causes that produces reasonable response times. If these two sets of causes could be isolated, action could be taken to improve the each process.

It should be noted at this point that the fact that the lower control limit is less than zero should not be a general cause for concern. As each process is improved and the response times become shorter and less variable, the center line on the x-bar chart will get closer to zero and the likelihood that the lower control limit will be less than zero will increase.

<u>Step 3--Bring the process into statistical control by removing special causes of variation</u>.

The urgent chart (Figure 18) for shop 451, the carpenter shop, shows the most control with only one point, sample number 7 on the R-chart, being out of control. Since the R-chart gives the measure of variability and determines the control limits for the X-bar chart it is important that it show statistical control before any attention is given to the X-bar chart.

One job in sample number 7 on this chart was responsible for the increase in the range. A discussion with the Chief of Resources and Requirements revealed that this was due to a delay in receiving an unusual part. It was not possible to employ any formal fault diagnosis techniques to identify the reason for this delay because the Chief of Operations chose not to commit any resources to the effort. In addition no action was taken to prevent this type of problem from

recurring. However, the Chief of Resources and Requirements did discuss several possible reasons for the delay and some possible corrective actions. This, in fact, completes the first step in a formal fault diagnosis process. The most important step, however, is identifying which is the actual cause and then formulating and implementing some corrective action. This latter portion was accomplished only as a paper exercise and not in reality. The results of this effort follow immediately.

The delay could have been caused by an error in the ordering process in material control. Several possibilities were discussed. The order form could have been lost either in material control, in the shop, or in transit. The wrong part could have been ordered due to a communication error. This could be due to either an inadequate description on the order form, failure to communicate the part description correctly to the vendor, or an error by the vendor that resulted in delivery of the wrong part.

A possible corrective action would be to keep this part in the material control stock. This would certainly prevent this particular delay from recurring but the cost might be too great. In addition, if this type of repair is infrequent the part maintained in stock may deteriorate or the corporate memory may not recall that such a part exists in stock the next time it is needed. This action was dismissed because it did not correct a root cause of the problem. It only corrected one symptom. The same problem could occur for the same reason over any number of different parts.

Another possibility is that the delay was invalid. This would be the case if the craftsman made a temporary repair that removed the

urgent condition. In such a case the completion time for the urgent job order should reflect the time the temporary repair was made, not the time the permanent repair was completed.

A possible corrective action would be to change the policy for closing out job orders. It is reasonable that an urgent or emergency job order could be considered complete as soon as the emergency or urgent condition was removed, even if the repair was only temporary. A routine job order could be initiated to handle the permanent repair when all the necessary parts are received.

Another possibility would be to increase the reliability of the distribution system to prevent delay or loss. Related to this would be an increase in the reliability of information transfer. There are many possibilities for error in this communication process.

One final possibility considered vendor reliability. If a more responsive parts supplier could be found it would be possible to reduce the delays due to this cause.

The response time measurement is a process performance variable. It serves as an indication of how well the squadron is providing job order service to the rest of the base. This measurement also has a direct relationship to the customer's quality requirements, so it is a valuable measurement to maintain. In order to diagnose some of these potential causes for delay, however, it will be necessary to apply statistical process control to more specific points in the process. The measurements at these points will be process state variables. Process state variables will be more closely related to potential problems than the response time. Measurements such as the vendor response time and vendor reliability would be process state variables.

These could be measured by counting the number of errors in each delivery or calculating the percentage of items in error. The instances of miscommunication when making an order is also a process state variable. No process state data, however, is currently being collected on the job order process.

The solution to the material delay problem and the process of bringing the urgent control chart for shop 451 into statistical control might go as follows. All the individuals involved with the processing of the job order that experienced the problem would meet to discuss why the job was delayed. This meeting may take the form of a brainstorming session or the more structured approach of the nominal group technique. Once a sufficient number of possibilities have been generated they would construct a cause-and-effect diagram as shown in Figure 23. The result of the discussion could be a consensus of opinion pointing to the job order policy as the root cause for this particular delay.

The group might agree that management should implement a change to this policy so that urgent and emergency job orders could be closed after temporary repairs have been made. A new routine job order would then be initiated to handle the remainder of the work when all materials are available.

The control charts would then be monitored for a period of time to look for any indication of change. This change may appear as a special cause of variation on the control chart. This would reveal itself as an out-of-control condition on the low side of the R-chart or an indication of a downward shift in the mean on the X-bar chart. On the other hand, it may only appear as a stabilization of the

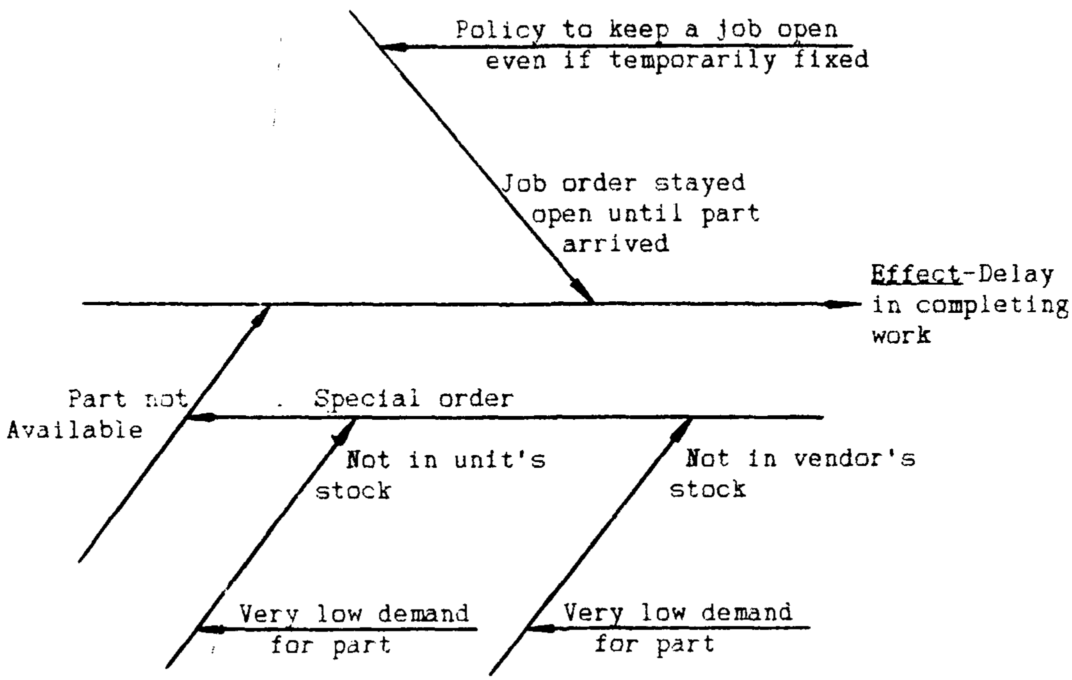


Figure 23
Cause-and-Effect Diagram
for Delinquent Job Orders

R-chart. If the process remains in statistical control for a period of time new control limits should be calculated.

The action described above did not make use of any process state variables nor require the implementation of a new process measurement. The cause of the problem was relatively easy to identify in this case, but this is not typical. More difficult problems will be more elusive and may require some trial-and-error before pinning the actual cause down. The trial-and-error process can be facilitated with the use of statistical process control. A potential trouble spot in the process can be analyzed with statistical process control using a process state variable, and management effort can be directed toward improving that portion of the process while observing the effect on the response time charts.

In discussions with management, the special cause described above seemed to be reasonably correct and they agreed that the change should be made. The benefits of such a change were discussed. They recognize that considerable effort is used to explain the reasons for delinquent job orders and if one of these reasons was eliminated the time saved could be used on more productive activities. No immediate effort was made to initiate this change, however.

If management change had taken place it would have been proper to remove point 7 from the control chart in Figure 18 and recalculate the control limits. Figure 24 shows this new chart. There are no out-of-control conditions, and the control limits and center lines are all at lower values. Continued use of this chart will provide more sensitivity to significant process changes and it will help management maintain the newly implemented changes.

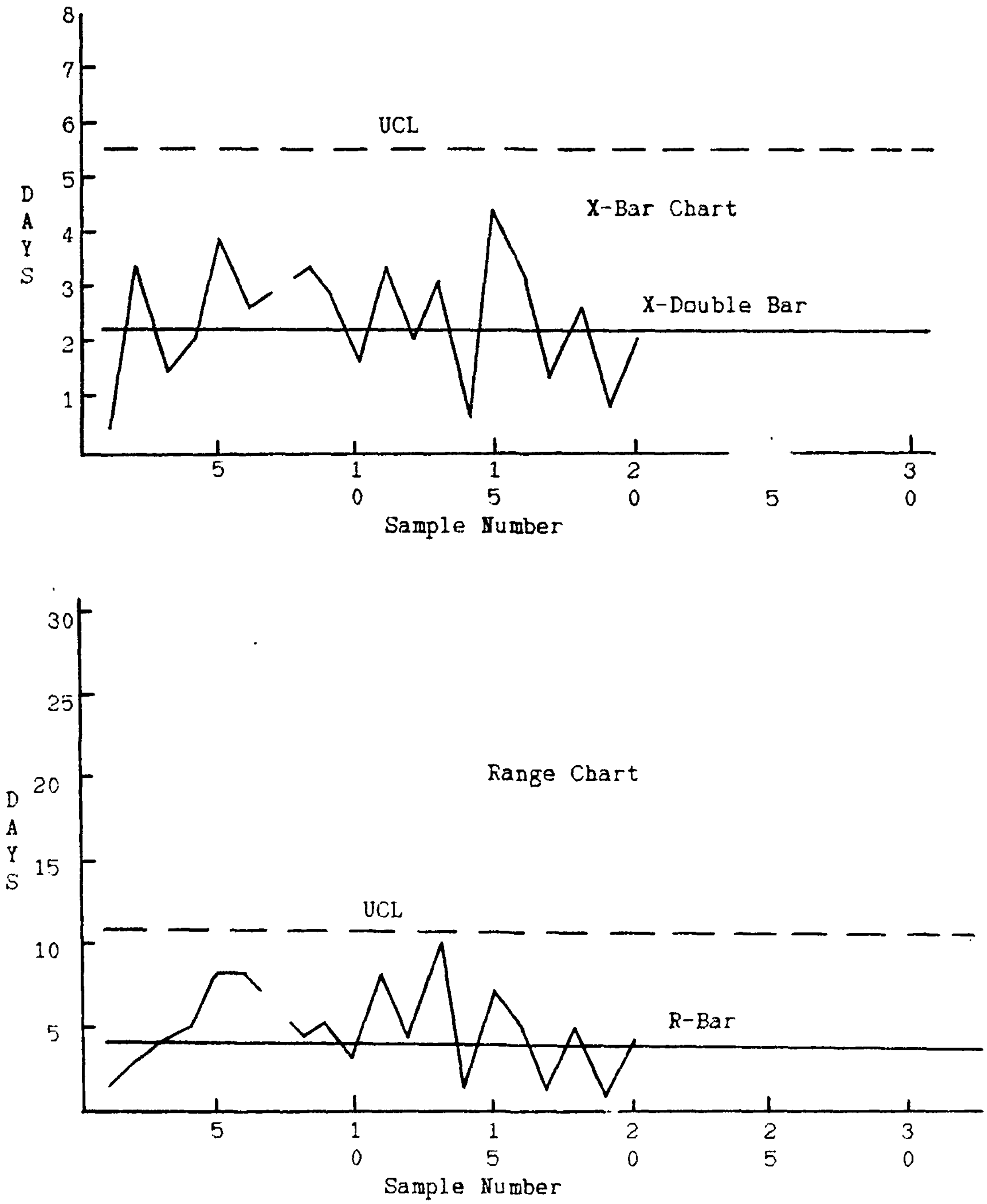


Figure 24
Urgent Job Order Response Time for Shop 451 with Point 7
Removed and Limits Recalculated

Also discussed was the possibility of implementing some process state measurements at key points in the process. One such measure was mentioned earlier--the percentage of errors in each delivery by each individual vendor. Statistical control at this point would provide a means to compare one vendor to another and identify changes in vendor performance. Such changes would identify any number of possible special causes, and not all of these could be attributable to vendor error. Some delivery errors most likely would be due to poor communication between the shops and material control, between material control and contracting, or between contracting and the vendors.

The goal of all of this effort is to bring the job order response time into statistical control for each shop. The identification of special causes of variation, such as poor communication, and the use of statistical process control on this process state variable are all aimed at reducing the variability of the response time. This may require several iterations through the first three steps of Stage 2 before statistical control is achieved.

Step 4--Maintain statistical control through the consistent use of the control charts.

Of course, once statistical control is achieved in any one of the measurements it should be maintained through the continual use of the control charts. This means taking action whenever an out-of-control condition presents itself. Each out-of-control condition is an invitation to find another means to improve the consistency of the process which would result in better output quality and greater productivity.

Step 5--Improve the process by identifying and removing common causes of variation.

Common causes of variation exist as background noise that causes the relentless variation in the process measurement as it appears on the process control chart. It would be unusual to take any measurement repeatedly over a period of time and not see the readings ever vary. For this reason common causes of variation do not appear on the control charts as out-of-control conditions and they are much more difficult to identify and remove. There are a few means available, however, that make this task a little more encouraging. The success of this task relies heavily on an individual's understanding of the process and the various events that effect its output.

Although it is difficult to experiment with administrative processes it can be done to a limited degree. In this case the studying of various process state variables using statistical process control is an elementary form of experimentation. A process state measurement is developed and control charts constructed. Various management actions are tested and the results monitored on the control charts. If a management action is successful it will appear on the control charts as an out-of-control condition. In this case the out-of-control condition will be in the direction of process improvement and management will want to make the cause permanent. Any time a sustained improvement is recognized the control limits should be recalculated to reflect the new statistical population.

Simulation is a means that can be used to experiment on the process without actually making any changes. A mathematical model is developed that simulates the actual functioning of the process under

study. Management action is tested using the simulation model and only those actions that show particular promise need to be implemented.

A simple simulation was developed for the processing of emergency job orders through the carpenter shop, shop 451. A queueing model was used with Poisson arrivals and generally distributed service times. The results of two trial runs are shown in Table 4. Trial 1 represents the process as it is currently operating. Trial 2 shows the impact of an improvement in response time consistency. Notice that a 20% reduction in the process variability results in nearly a 40% improvement in the expected amount of time a job order spends in the system without actually reducing the average response time. This provides conclusive evidence that the process and workers do not necessarily have to work faster to accomplish an improvement in their average emergency job order response time. A mere improvement in consistency, accomplished by insuring that excessively long delays are prevented, will result in dramatic improvements. Simple simulations such as this can serve as guides for management in directing their improvement efforts.

Simulation does have its limitations, however. The larger the system is the more complicated the simulation model will be. It is also difficult to simulate the effects of management changes on worker attitude and motivation, and these variables are especially critical in administrative processes. There are other variables in non-manufacturing activities that are simply not amenable to adjustment. It is not possible, for example, to adjust the degree of attention a

Table 4

Results of Two Queueing Simulations

Simulation 1. Model of emergency Job order processing for shop 451

Emergency job arrival rate = 1.94 each day

Average service time = 1.35 hours

Service time standard deviaiton = 6.8

Expected number in the system = 1.26

Expected waiting time in the system = 5.19 hours

Simulation 2. Model with reduced service variation

Emergency job arrival rate = 1.94 each day

Average service time = 1.35 hours

Service time standard deviaiton = 5.0

Expected number in the system = 0.8

Expected waiting time in the system = 3.33 hours

worker pays to his work, yet lack of attention is a major cause of errors.

Stage 3--Improvement propagation.
Step 1--Continually refine the process.

In order to proceed to Stage 3 a manager must be confident with the statistical control of his own processes. There are three basic levels of confidence a manager can have in his processes. The first level of confidence is indicative of a manager who has not made use of statistical process control. His confidence about the performance of his processes is reflected in the following statement. "I do not know why there are so many delinquent job orders." The second level of confidence is indicative of a manager who is using statistical process control and has processes that are in statistical control. He is able to say, "I know why we have this many delinquent job orders." The third level of confidence is indicative of a manager who has made use of statistical process control for a long time and has been able to remove many significant common causes of variation in his processes. He can say with confidence, "I know why we do not have any delinquent job orders."

It is not necessary to reach this final level of confidence in order to engage suppliers in the improvement effort. It is necessary, however, to have the processes in statistical control.

Carrying the hypothetical situation one step further, consider the Chief of Material Control who has been concerned about the quality of the material descriptions on order forms arriving from the planning section. Suppose he has done everything possible within his section to insure that these descriptions are complete and accurate. He is

maintaining process control charts on the number of delivery errors due to inadequate descriptions, but still the wrong material is being delivered to the shops on occasion and causing delays in job completion. This activity would satisfy the requirements of Step 1.

Step 2--Communicate quality requirements to suppliers and assist them in applying statistical process control.

Step 2 would require a candid meeting between the Chief of Material Control and the Chief of Planning to discuss material control's quality requirements for incoming order forms. The Chief of Material Control should be willing to assist the Chief of Planning in implementing statistical process control within his section to improve the outgoing quality of his purchase requests.

A successful implementation of statistical process control in planning would improve the productivity of both sections and improve the overall system performance.

The Job Stoppage Example--Use of c-Charts

This completes the sequential discussion of the implementation steps. Following is a discussion of several other efforts within the operations branch to apply statistical process control. These will be discussed within the context of the implementation steps but each step will not be discussed explicitly.

The planning section plays a key role in the processing of the more substantial work orders. Although some job orders are large enough to require detailed planning, most of the large jobs on an Air Force base are done through the work order process. Planning is a key element in the processing of work orders.

The planning section produces two key products. One is the Air Force Form 327, work request. Planning receives the work request from production control. The work request contains a brief description of the work. The planner makes a rough estimate of the cost of the job and submits the work request to the proper authority for approval. The approval authority is based on the cost of the work. The more the project costs, the higher ranking the approval authority must be. The range of approval authority extends from the Chief of Production Control through the installation commander and as far as the Department of Defense and Congress.

The second key product of the planning section is the Air Force Form 332, Work Order, and several other documents that comprise the completed work order package. A completed work order package contains detailed plans for the project, purchase requests for the correct amounts of all required materials, and a job phase calculation sheet that describes the work sequence in detail, including duration estimates for each phase.

The following example is given to demonstrate various difficulties encountered in gathering and analyzing the correct data. One process performance variable being monitored by management was the number of work orders on job stoppage status. This number was reported weekly at the Commander's Update meeting. A work order is placed on job stoppage if something has occurred that causes the work to be interrupted. This is a key element in the customer's perception of the quality of the service he receives from the civil engineering squadron. When a job stands idle the work site is left in a state of disorder which often causes considerable inconvenience for the custom-

er. It may also deprive the customer of the use of a portion of his facility. The longer the job is on job stoppage the greater the customer's irritation and dissatisfaction becomes.

This organization behaves as most organizations do when it comes to controlling this type of variable. As long as the number of work orders on job stoppage seems low management is content, but if this number begins to rise management demands explanations and corrective action whether this is actually needed or not. There is usually little anyone can do to correct the problem so the best that can be offered to management are excuses, and the worst that can happen is that the situation is concealed for a time.

Statistical process control was applied to this variable knowing that it was a process performance measure for the work order process. The purpose was to gain a better understanding of this measurement so that corrective action can be properly applied and over-control prevented. Another anticipated gain was the shift in the motivation for corrective action to lower levels in the organization. Instead of the commander demanding explanations and actions, those directly involved would already be engaged in corrective action and have a complete understanding of the cause for the increase.

A file of the weekly report slides was available for the past three years. Each slide contained a list of work order numbers on job stoppage and the reason for the stoppage. Putting this in manufacturing terms, the week's worth of work was considered one unit of output, and each instance of a work order on job stoppage was considered a defect in this unit of output. Each different reason for stoppage comprised a separate class of defects. The initial gathering of data

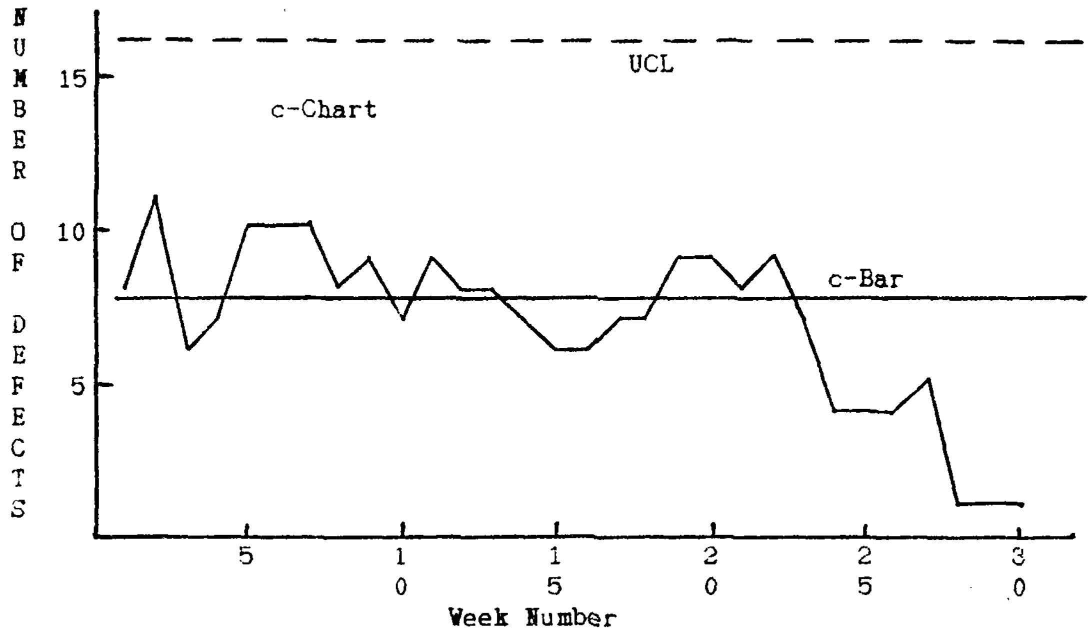
identified thirteen separate types of defects that could occur in one week's worth of work. These are listed in Table 5.

Figure 25 shows a portion of the c-chart constructed using this data. The chart does not show any extreme points (points beyond the control limits), but the control limits are wide because there is a large amount of variation in the data. The process is basically in statistical control up to about week 25, but there are two out-of-control conditions following this that are indicated by sustained runs above and below the mean. The first out-of-control point is week 30 which is the end of a run of eight points below the mean, and the two points that follow are also out-of-control conditions. The probability of this occurring by chance (ten points in a row below the mean) is less than one out of a thousand. (This is a Poisson distribution with mean of 7.84. The probability of one point being less than 7.84 as obtained from a Poisson table is about 0.476. The probability of ten points in a row is, therefore, $(0.476)^{10}$ which equals about 0.0006.) The second out-of-control condition begins with week 39 which is the end of a similar run above the mean. This presents strong statistical evidence of a sustained upward shift in the process mean that lasted for at least sixteen weeks. The probability of this occurring by chance is less than one in ten thousand. (The probability of being greater than or equal to 7.84 is 0.534 from the Poisson tables. The probability of sixteen points in a row is $(0.534)^{16}$ or 0.00004.) Both out-of-control conditions imply that special causes of variation are at work in the process. Unfortunately, an examination of the office records and discussions with the personnel who were involved failed to reveal what these causes might be.

Reasons for Job Stoppage

Table 5

1. Waiting for materials.
2. Waiting for contractor to complete a task.
3. Continue work only as required.
4. Lack of scheduled man-hours.
5. Stop due to inclement weather.
6. Waiting to regain access to a facility.
7. Job reprogrammed for a later date.
8. Returned for additional planning.
9. Waiting for decision to continue.
10. Waiting for Consolidated Maintenance Squadron (CMS) to complete a task.
11. Waiting to receive equipment to be installed.
12. Waiting for concrete to cure.
13. Waiting for Army assistance.



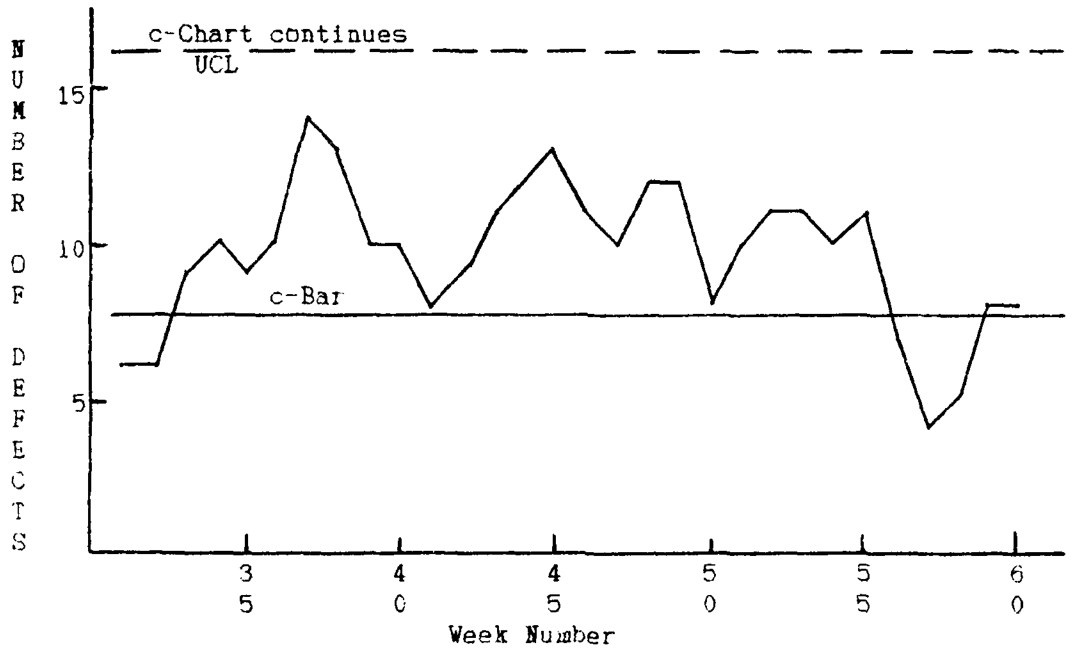


Figure 25
Work Orders on Job Stoppage per Week
Due to 13 Reasons

Since nothing conclusive could be determined from the control chart, a Parato analysis of the data was conducted. This Pareto chart is given in Figure 26. Almost 40 percent of the job stoppages were due to material shortages. On further discussion of the reasons for delay, it was discovered that several of the reasons listed did not indicate poor service delivered to the customer but was in fact a favor for the customer. An important item to consider in analyzing the data is that it must measure what it is intended to measure. The problem in this case was that the quality characteristic was not adequately defined. Work orders were considered to be on job stoppage as long as the work order was still open and no progress was being made during the week in question. No regard was given to the reason for this action. The third most frequent reason for stoppage--continue work only "as required"--was actually a work order that provided the customer a specific type of assistance over a relatively long period of time, and this assistance was only provided when the customer required it. At other times the work order was placed on job stoppage. It was clear that counting these as defects was not correct. In non-manufacturing settings it is often difficult at first to differentiate between what is defective and what is not defective. That is why it is important to carefully analyze the data to be sure it is actually measuring what you want it to measure. In this case the "as required" reason and three others (access, CMS, and equipment) were not measuring a work delay caused by the civil engineering organization. Rather they measured work delays caused by the customer or for the benefit of the customer. In fact, the "as required" reason

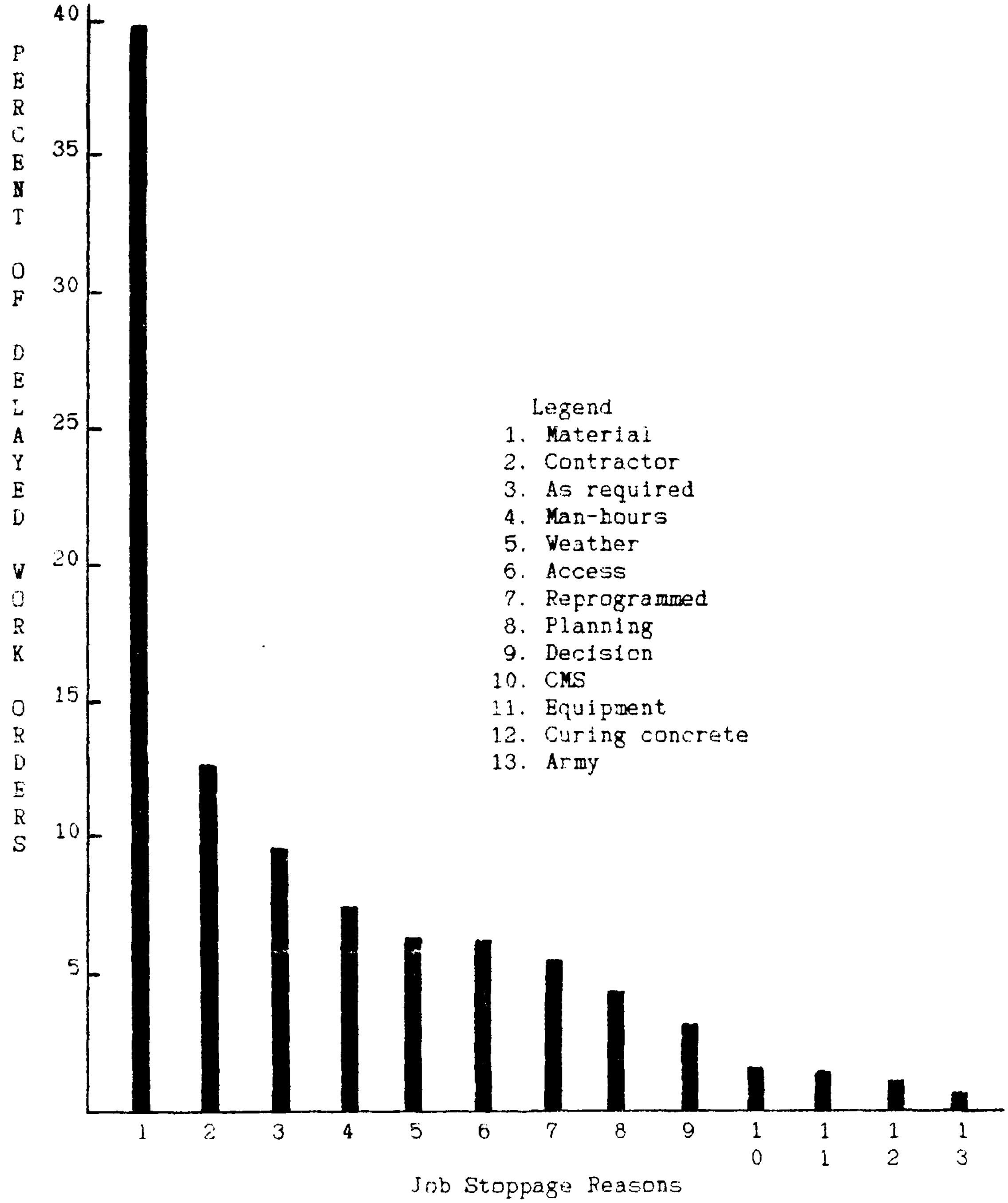


Figure 26
Distribution of Reasons for Job Stoppage

was not a delay at all, but simply a planned hiatus in the progress of the job.

These reasons were removed from the data base and another c-chart run. This chart is shown in Figure 27. Although no extreme points exist there are several instances that indicate a shift in the average performance has occurred. Week 30 indicates again that some forces are causing the number of work orders that are on job stoppage to be less than the previous average, and an upward shift in the process average is again evident between weeks 32 and 50. (Actually there are two runs above the mean during this period because week 41 is below the mean.) The removal of the four incorrect reasons for delay did not substantially change the statistical behavior of the control chart so, again, no special causes for these changes were discovered.

An additional item to be considered is the fact that one week's data is not completely independent from the previous week's data because many work orders remain on the job stoppage list for more than one week.

A count of only the new work orders placed on job stoppage each week eliminated this dependence. The resulting c-chart is shown in Figure 28. No sustained runs occur either above or below the mean, but an abrupt increase is indicated by the out-of-control point at week 35. This point indicates that a special cause was in effect at that time that caused the average to temporarily shift upward. There are also a number of times when the chart touches zero. In this case zero is also the lower control limit. These points need to be considered to determine if they can actually be due to the existing set of common causes of variation, or if some special cause of variation is

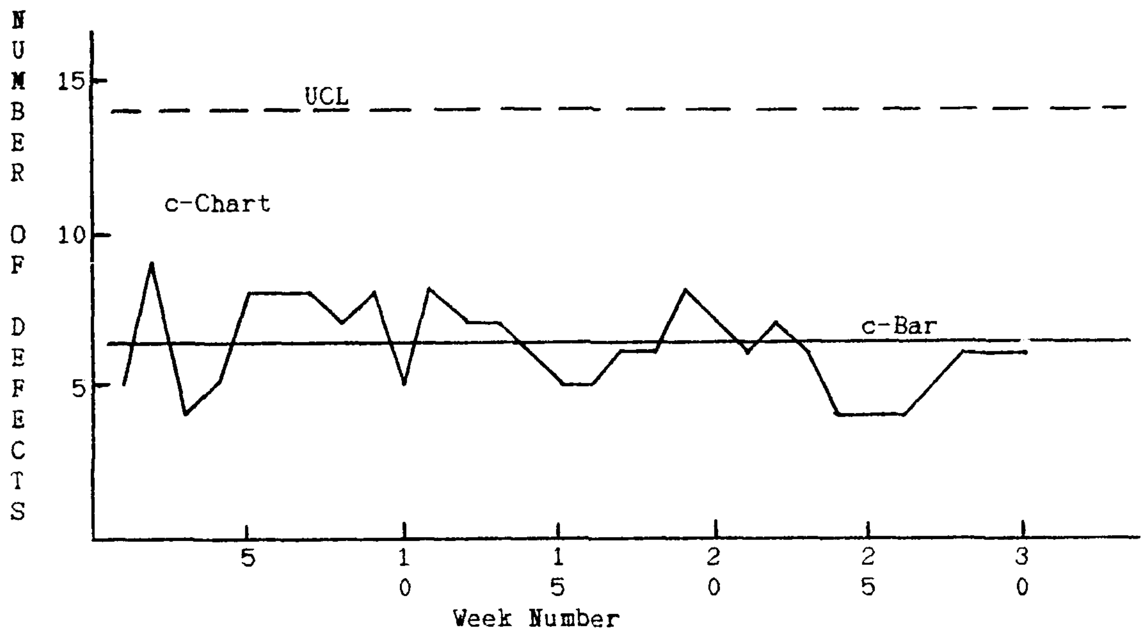
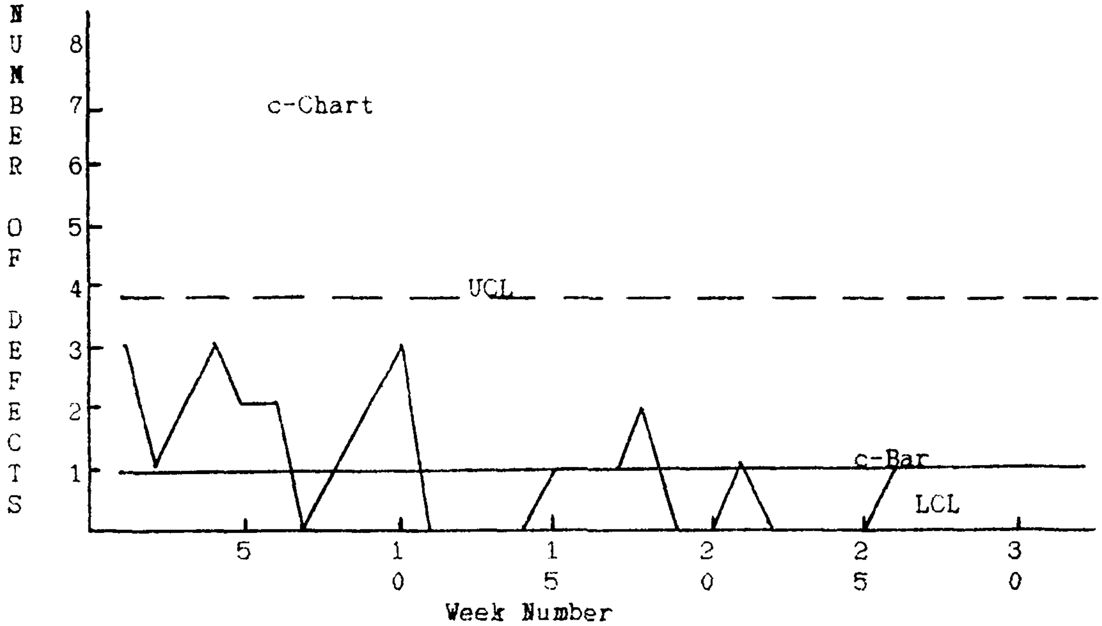


Figure 27
Work Orders on Job Stoppage per Week
Due to 9 Reasons
(As required, access, CMS, and equipment removed.)



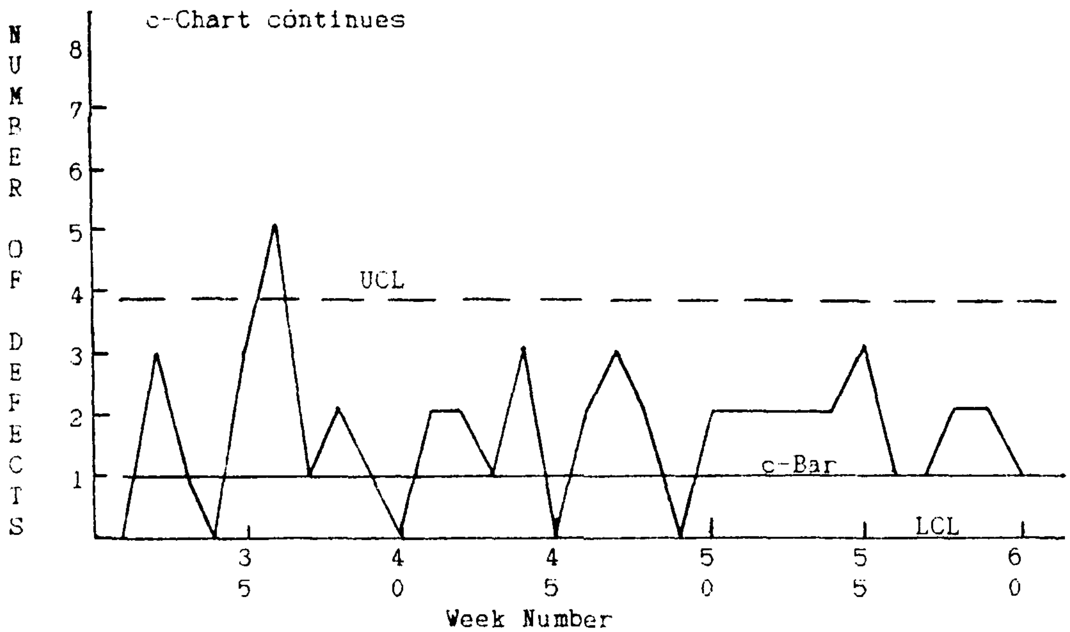
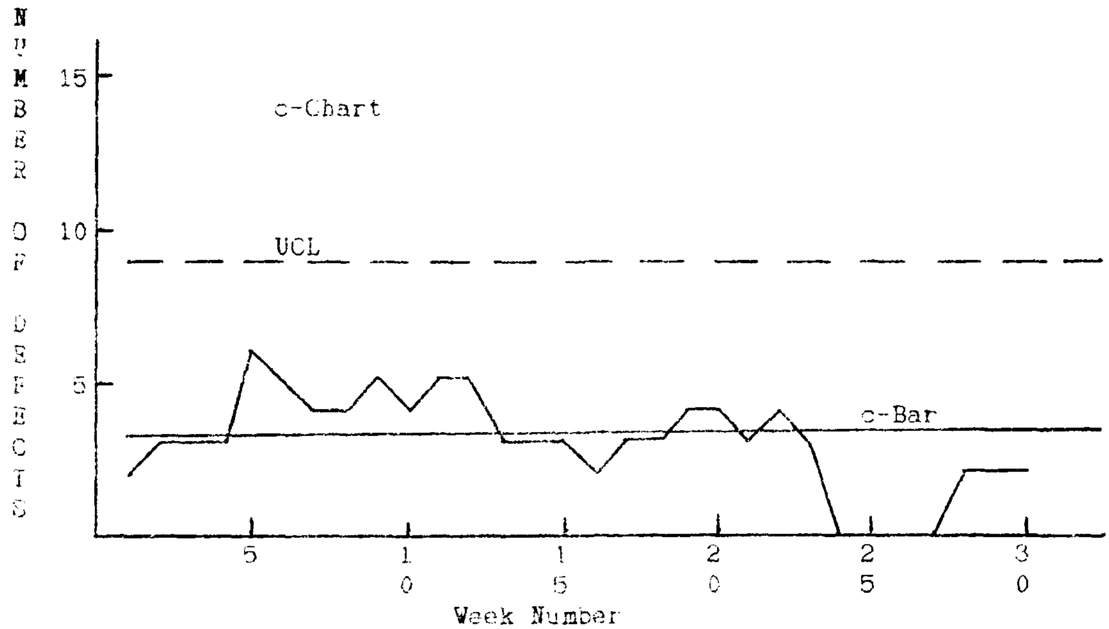


Figure 28
New Work Orders on Job Stoppage per Week
Due to 13 Reasons

present that should be identified. In this case sixteen out of the sixty points were zero. A Poisson distribution with a mean of about one would be expected to have about one-third of its points on zero so it is not possible to say that a special cause of variation is at work. By removing the dependency in the data the chart became more sensitive to special causes of variation, yet still measured the desired process performance. Unfortunately, it was not possible to conduct an in-depth study of the process to determine the cause for this out-of-control condition. The example does, however, serve to illustrate how statistical process control can be used to identify when a special cause of variation is acting on the process and this clue gives management a good place to begin an investigation. It also prevents unproductive effort due to over-control by management.

One additional consideration when collecting this type of data is that a work order may be placed on job stoppage for more than one reason. Since the reason for job stoppage is the data that is desired, it is important that all reasons for job stoppage are recorded. This possibility was discussed with management and they agreed that on some occasions there may be more than one reason for a single work order to be delayed.

Another approach to take is to concentrate on the most prevalent reason for job stoppage. In this case that would be a shortage of materials (see Figure 28). Figure 29 is the c-chart constructed using this data. The chart shows that the process is not in statistical control. There are two runs above the mean (between weeks 5 and 12, and weeks 41 and 49) and one run below the mean (between weeks 23 and 26). This chart uses the total number of work orders on job stoppage



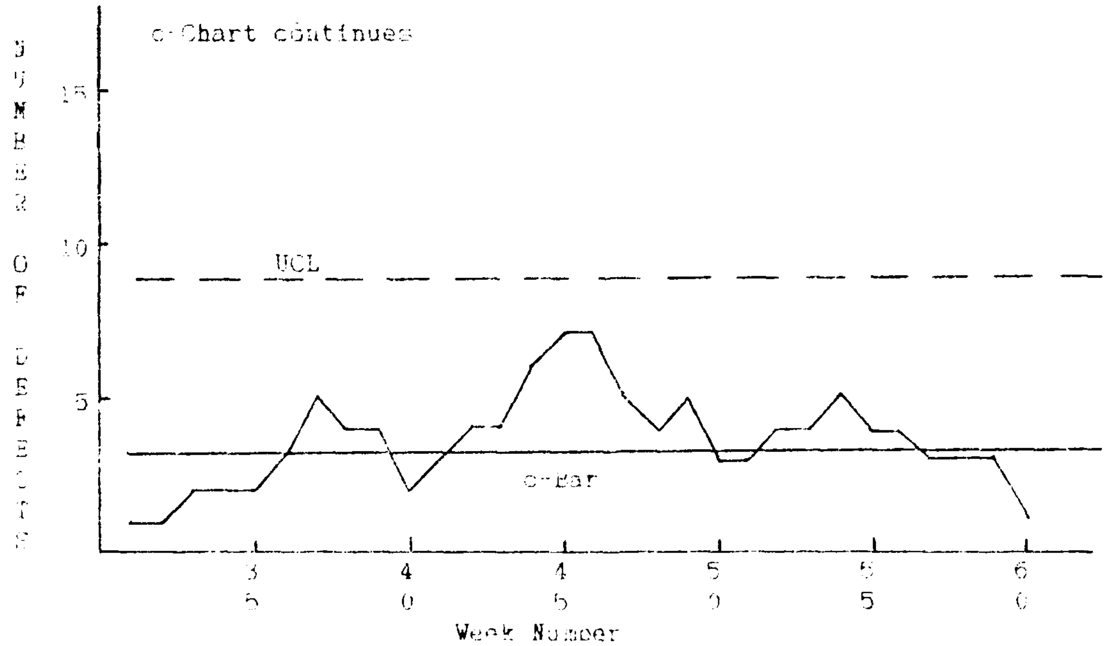
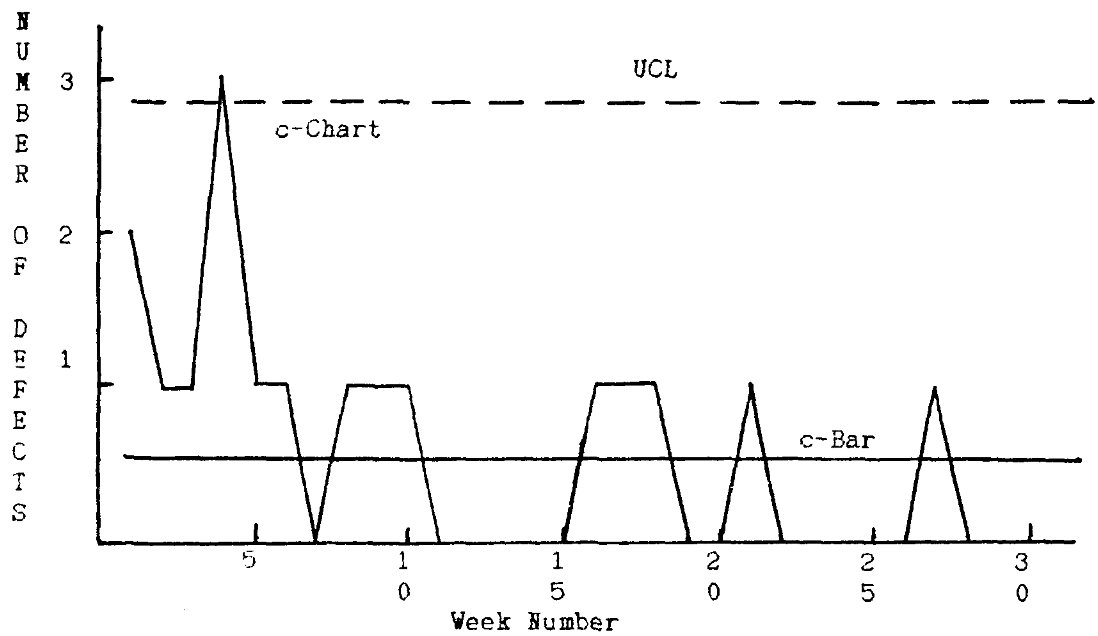


Figure 29
Work Orders on Job Stoppage per Week
Due to Material Only

each week due to material shortage, so the data points are not independent which increases the likelihood of runs in the data. Figure 30 shows the chart with this bias removed in the same manner that it was removed previously.

Notice that nearly half of the points in Figure 30 are zero. Although this is not statistically significant ($P(x = 0) = (0.57)^0 e^{-0.57}/0! = .565$ where the mean = 0.57. To be statistically significant, the number of zero points would have to be greater than about six-tenths of the total.) it indicates that the opportunity space for the occurrence of defects should be expanded. The fact that c-bar is less than one adds weight to the previous statement. This data is analyzed again with an opportunity space of a month rather than a week. The chart of this data is given in Figure 31. Although there is an insufficient number of points on this chart to judge whether or not the process is in statistical control, it does show better statistical behavior than the previous chart with an opportunity space of one week. No out-of-control conditions are apparent. The main advantage of this chart is that it will be more sensitive to changes due to special causes of variation. A disadvantage is the paucity of data points and the long time span between points. However, as the process is improved this disadvantage will fade because sampling will be required less frequently.

These measurements, particularly the ones concerning material and man hour shortages, reprogramming, and additional planning are of special concern to the Chief of Planning because they reflect the quality of the plan produced by his section.



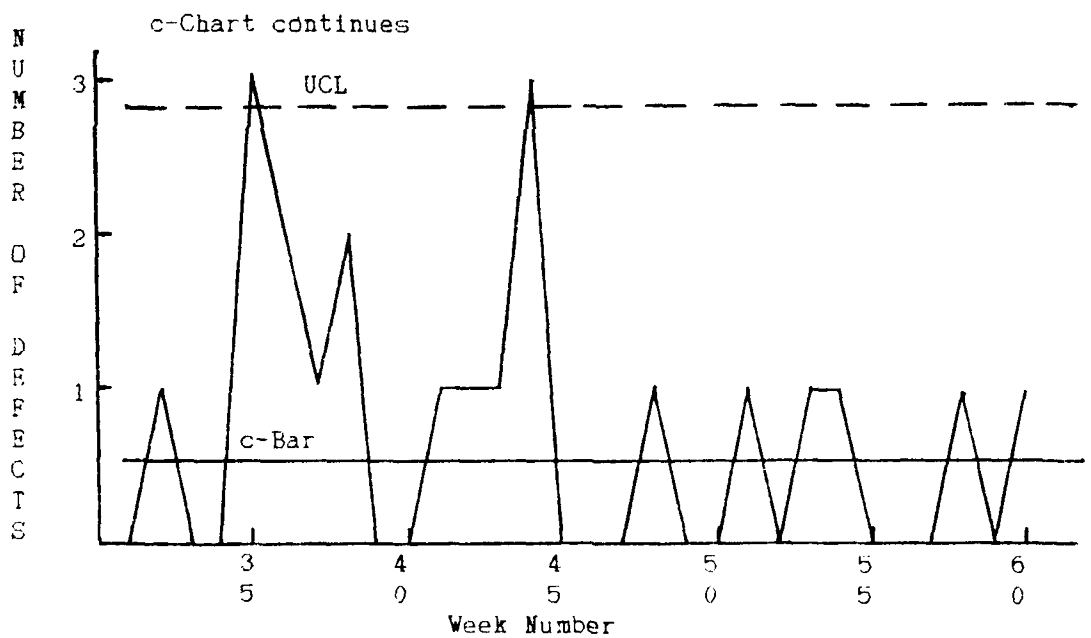


Figure 30
New Work Orders on Job Stoppage per Week
Due to Material Only

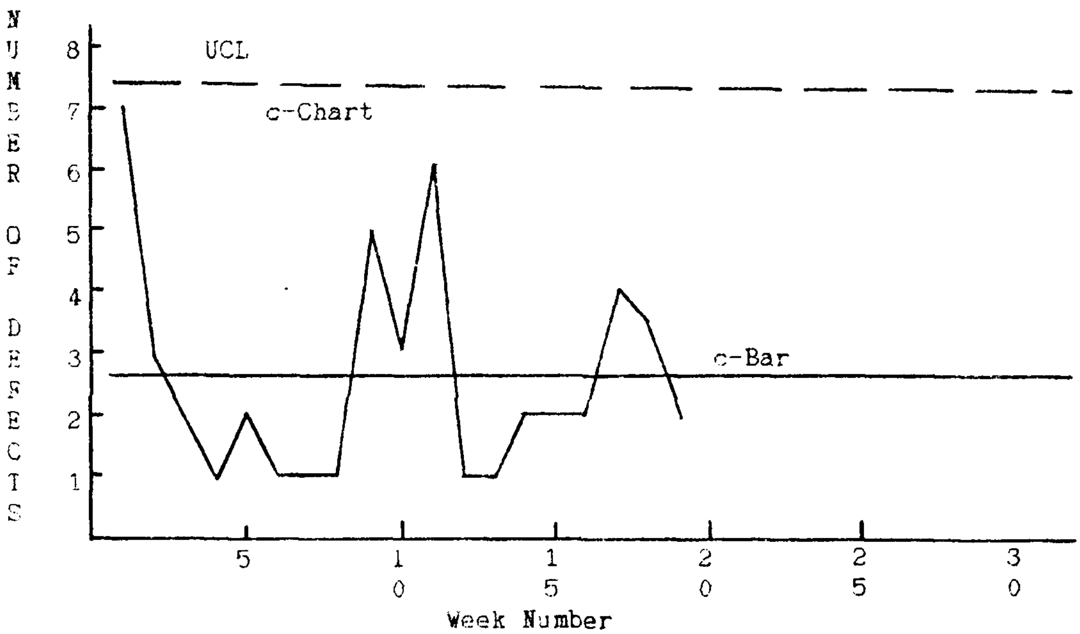


Figure 31
New Work Orders on Job Stoppage per Month
Due to Material Only

Process Capability

In many non-manufacturing instances the idea of process capability has little meaning because there are no explicit specifications. There are some instances, however, where a process capability analysis has the same meaning as in a manufacturing setting. The job order response time is an example of this. In order to conduct a meaningful process capability analysis, the process must be in statistical control. The urgent job order chart for shop 451 (Figure 18) was nearly in statistical control except for point 7 on the R-chart. If the cause for point 7 being out of control could be identified and removed this point could be removed from the chart analysis and the process considered to be in statistical control. This was discussed earlier in the chapter (refer to Figure 24). A process capability study will be conducted using this data.

A CPU index (also called a C_p Upper index) will be used for this analysis (Kane 1986). The following general formula is applicable to most process capability studies: allowable process spread divided by the actual process spread. The CPU index is used for processes that have only an upper specificaiton limit and the mean of the process is also taken into account. This is unlike the C_p index that can show a process to be fully capable yet, if the process is not centered, its potential capability will not be realized. The allowable process spread for a CPU index calculation is determined by subtracting the process average from the upper specificaiton limit (USL − μ). The actual process spread is obtained by multiplying the process standard deviation by three (3σ). Estimates of these two values are calculated using X-bar and s instead of μ and σ, respectively.

Now to apply this to the urgent job order response time for shop 451. The average response time (X-bar) is 2.26 days and the estimate of the process standard deviation (s) is 2.44. The upper specification limit (USL) is five days. The CPU index is, therefore, $(5 - 2.26)/3(2.44) = 0.374$. A CPU index of 1.0 implies that approximately 0.135% of the process output will be beyond the specification limit. This is half of what is expected from a process with bilateral specifications that has a C_p index of 1.0. A CPU of 0.374 is very poor and implies that over 13% of the response times will be beyond the five day specification limit. It is obvious that this process is in dire need of improvement.

The process data is not well represented by the normal statistical model because the data is skewed toward zero. Taking this into account would increase the capability somewhat, but not appreciably. Considerable effort will be required to increase this process capability to a point where the manager can say with confidence that the carpenter shop is able to respond to an urgent job order within five days.

There are two basic ways to effect an improvement in the CPU index. One is to decrease the process mean. This will increase the value of the numerator of the index. The other way to improve the index is by decreasing the natural spread of the process. This will decrease the denominator of the index. This is the ultimate goal of statistical process control--to increase process performance consistency and capability. Continual improvements in process performance will result in increased process capability and increased confidence in the shop's ability to keep its promises to their customers.

It should be re-emphasized here that specification limits should be considered temporary cutoff points. This notion will preclude someone from becoming content with a moderate level of process improvement. Continual improvement should be pursued no matter how capable the process becomes.

Conclusion

Two non-manufacturing processes in an Air Force civil engineering squadron were selected for study. The complete implementation process described in chapter 5 was applied to job order response times, and X-bar and R-charts were used to analyze the data. The job stoppage process was studied using c-charts. And, finally, a brief process capability study was conducted on the urgent job order response time for the carpenter shop.

It is evident from this brief encounter that there is a vast potential for improvement in at least these two processes. It is safe to expand this conclusion to other processes within the squadron and to non-manufacturing processes in general. Statistical process control is a valuable tool for the manager of non-manufacturing operations.

It was observed that non-manufacturing processes are particularly resistant to measurement and improvement efforts. This may not be unlike the inertia present in manufacturing processes as well, but this resistance seems to be greater in the non-manufacturing environment. Measurement of non-manufacturing processes are generally direct measurements of personal performance and most people feel threatened by this scrutiny.

This case study, unfortunately, was not able to demonstrate the results of improvement efforts prompted by the use of statistical process control. It was able to show, however, that non-manufacturing activities are amenable to statistical analysis and that the first result of such analysis is the initiation of constructive thinking about process performance and improvement efforts. It was also demonstrated that non-manufacturing activities are not dissimilar to manufacturing activities when the various elements of a process are defined in their broadest terms.

Efforts will continue on these processes in the future in an attempt to succeed in achieving statistical control and process improvement.

CHAPTER 7
Conclusion

The purpose of this thesis was to translate the concepts and techniques of statistical process control into terms useful to managers of non-manufacturing activities. Three objectives were added in support of this purpose: 1. persuade managers that statistical process control is an essential management tool, 2. provide managers a means to employ statistical process control in their individual areas of responsibility, and 3. that individual first-line management effort is effective in bringing about quality and productivity improvements.

Non-manufacturing activities pervade our entire economy and employ more of the work force than manufacturing activities do. Even within a heavy manufacturing company a majority of the jobs involve non-manufacturing activities. This demonstrates the enormous potential for quality and productivity improvements through the use of statistical process control.

Central to the correct use of statistical process control is an individual's understanding of quality and how quality and productivity relate to each other. Quality is defined as loss due to functional variation (Taguchi 1982) and this general definition can be reflected in more specific definitions such as this: Our quality policy is to reduce variability in everything we do (Scherkenbach 1985).

Quality improvement through process control always results in improved productivity and competitive position, because every cause of process variation is a source of waste and inefficiency. Taguchi's loss function (Taguchi 1982 and Hunter 1987) provides the economic incentive for continual, never-ending process improvement.

The cost of quality can be considered from two perspectives; how much does it cost to have a high level of quality and how much does it cost not to have a high level of quality. The costs of not having quality far out-weigh the costs of improving quality through the proper use of statistical process control.

These concepts form the argument to convince management that statistical process control is an essential management tool. The historical use of quality control concepts in manufacturing can mislead well-intentioned managers because the majority of quality improvement efforts in manufacturing are still product oriented. The correct approach to quality improvement is through a process orientation.

Manufacturing and non-manufacturing activities have some differences, but it is easy to emphasize and exploit their similarities in order to understand and employ the concepts and techniques of statistical process control to a wide variety of processes. Central to this understanding are the concepts of the customer, producer, process, and product. These concepts are common to all activities.

There are some differences of opinion among quality professionals concerning the similarities between manufacturing and non-manufacturing activities, and the applicability of standard quality control concepts to non-manufacturing activities; but the school that advocates that there is essentially no difference and that statistical process control is equally applicable to non-manufacturing activities is continuing to grow.

The techniques of statistical process control consist mainly of Shewhart control charts. The distinction between special and common causes of variation is vital to the proper use and interpretation of

these control charts. A concise set of rules exist to aid in the interpretation of control charts (Nelson 1984). Another result of the use of statistical process control is the avoidance of the dual problems of over-control and under-control of a process.

A key step in process improvement is successful fault diagnosis. The following tools and methods are among those available to aid in this effort: Ishikawa cause-and-effect diagram, Pareto analysis, simulation, design of experiments, nominal group technique, and brainstorming.

The implementation of statistical process control is divided into three stages:

STAGE 1--Define the process.

STAGE 2--Apply the techniques of statistical process control.

STAGE 3--Propagate quality/productivity improvement.

This process not only aids in the use of statistical process control, but also leads the manager to a better understanding of his operations and his immediate work environment.

This implementation process is effective in any work situation and for any process. Its use was demonstrated through two separate processes in an Air Force civil engineering squadron.

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